

Fall 2019 IceBridge Antarctic Flight Plans  
4 October 2019 Draft

*compiled by*

John Sonntag

# Introduction to Flight Plans

This document is a translation of the NASA Operation IceBridge (OIB) scientific objectives articulated in the Level 1 OIB Science Requirements, at the June IceBridge planning meeting held at the University of California at Irvine, through official science team telecons and through e-mail communication and iterations into a series of operationally realistic flight plans, intended to be flown aboard NASA's G-V aircraft roughly from mid-October to early-December 2019. The material is shown on the following pages in the distilled form of a map and brief text description of each science flight.

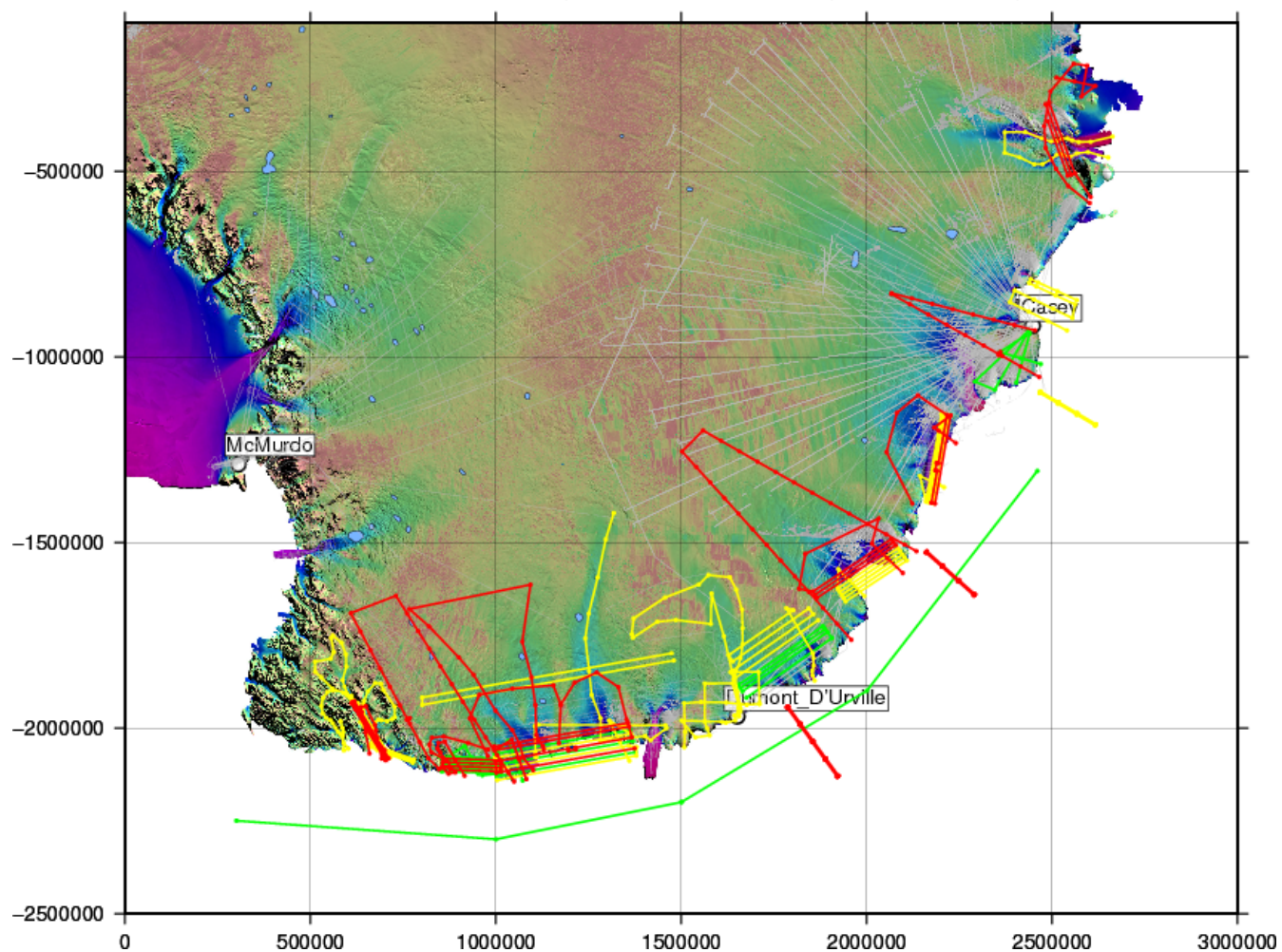
For each planned mission, we give a map and brief text description for the mission. The missions are planned to be flown from Hobart, Tasmania. A careful reader may notice that some of the mission maps in the main part of the document highlight flightlines in green, yellow, and red colors, while other only show the black or red lines. The colors are a refinement added to the flight plans at a late stage of design which help the field team navigate the aircraft properly to achieve specific science goals. The colors represent the degree of “straightness” of each flight segment, where straight segments are steered using an automated technique and curved sections using a specialized manual method. Not all of the flight plans shown here have necessarily reached that mature stage of design.

In fact, as a general rule the flight plans depicted here are all at varying stages of completeness. For each mission we note “Remaining Design Issues” to be resolved, if any exist. In most cases these are minor. ICESat-2, CryoSat-2 and Sentinel 3a underflights are a major exception, since these have to be re-planned for each potential flight day (for sea ice) or within a window of several potential flight days (for land ice). Sea ice camp/site overflights are also an exception, since these move with the motion of the ice, unless they are situated on shore-fast ice.

Note that this document shows 27 planned land ice and 6 planned sea ice missions, which is more than we expect to fly this year. The extra flight plans give us operational flexibility to fly as much as possible, and scientifically productive, while we are in the field. The entire suite of 33 flight plans is depicted in the introductory material following this text. Each flight has a priority assigned to it by the OIB science team, either high, medium or low, and these are listed below with each mission.

# Prioritized 2019 OIB Antarctic Flights

red=high(14) yellow=medium(13) green=low(6)



# Sea Ice – Coastal East

This mission is designed to survey sea ice near off the coast of Victoria Land. This mission does so in a zonal manner, examining gradients in sea ice thickness and snow cover from east to west.

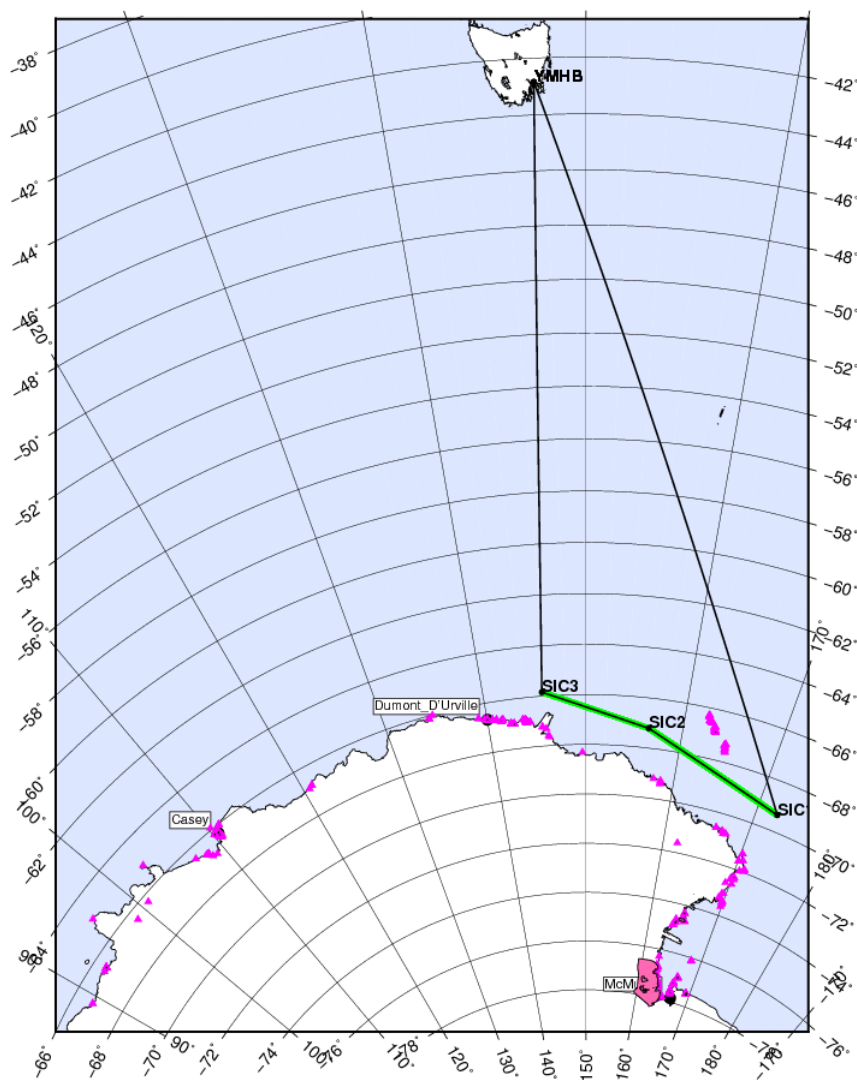
**Flight Priority:** low

**ICESat-2 Tracks:** none

**Remaining Design Issues:** none

## Sea Ice – Coastal East

9.2 hours total / 2.6 hours survey



# Sea Ice – Coastal West

This mission is designed to survey sea ice near off the coast of Wilkes Land. This mission does so in a zonal manner, examining gradients in sea ice thickness and snow cover from east to west.

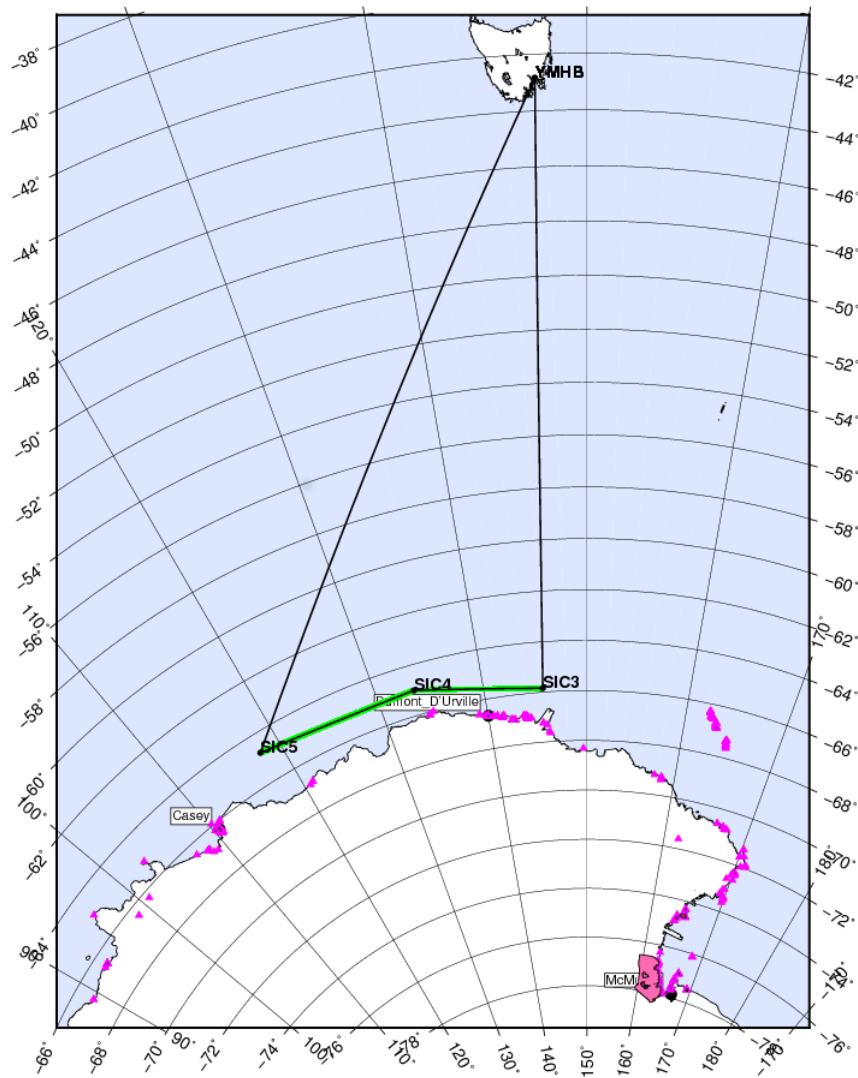
**Flight Priority:** low

**ICESat-2 Tracks:** none

**Remaining Design Issues:** none

## Sea Ice – Coastal West

9.1 hours total / 2.8 hours survey



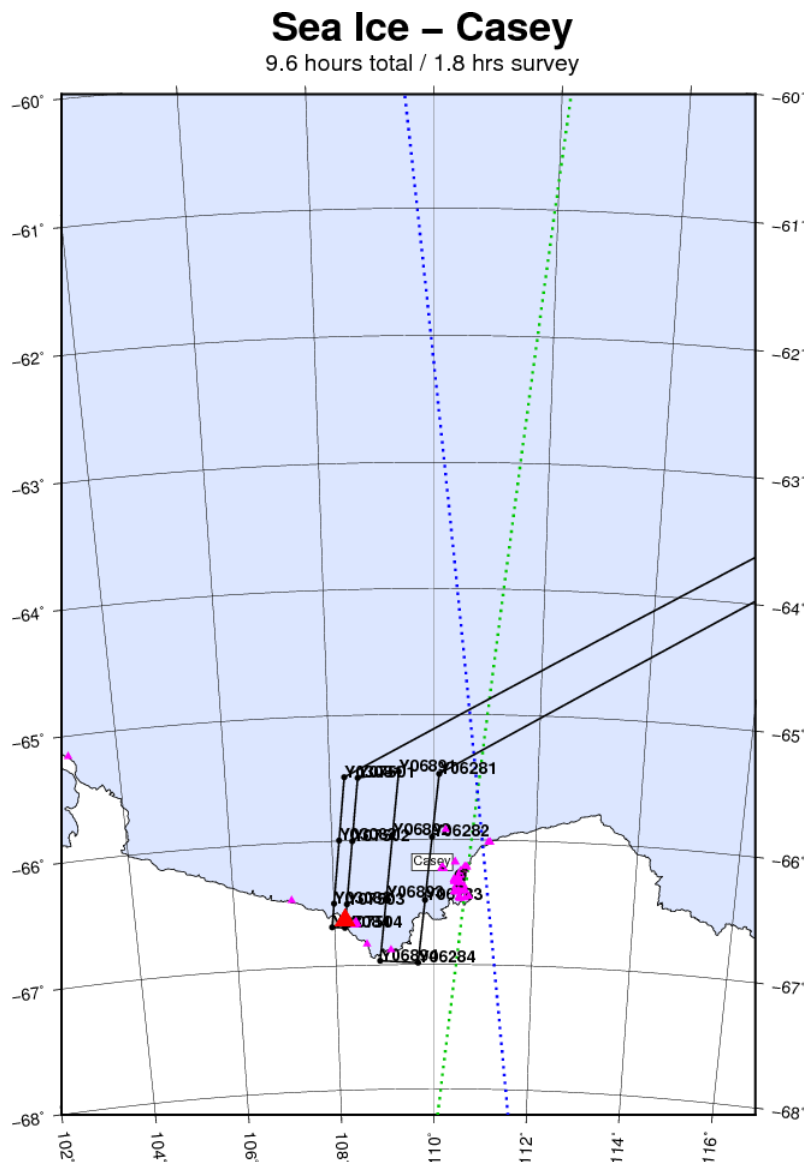
## Sea Ice – Casey

This mission is designed to survey sea ice near Casey Station, primarily along ICESat-2 ground tracks. We pay particular attention to shore-fast ice for this flight. As of this writing, Australian proposals for collection of in-situ data on the fast ice near Casey Station were being evaluated. We expect to modify these lines according to the success of those potential data-gathering efforts, in order to coordinate the airborne and in-situ data collection. As of this writing we expect to target IS-2 RGTS to occur on 7 November 2019, and also on 3 November 2019. The fast ice portions of this mission should be flown at 1500' AGL.

**Flight Priority:** medium

**ICESat-2 Tracks: Y0308,Y0628,Y0689,Y0750**

**Remaining Design Issues:** align one or more lines with fast ice Australian data sites; RGT 0567/green is the sea ice study site line, RGT 0773/blue is the land ice study site line



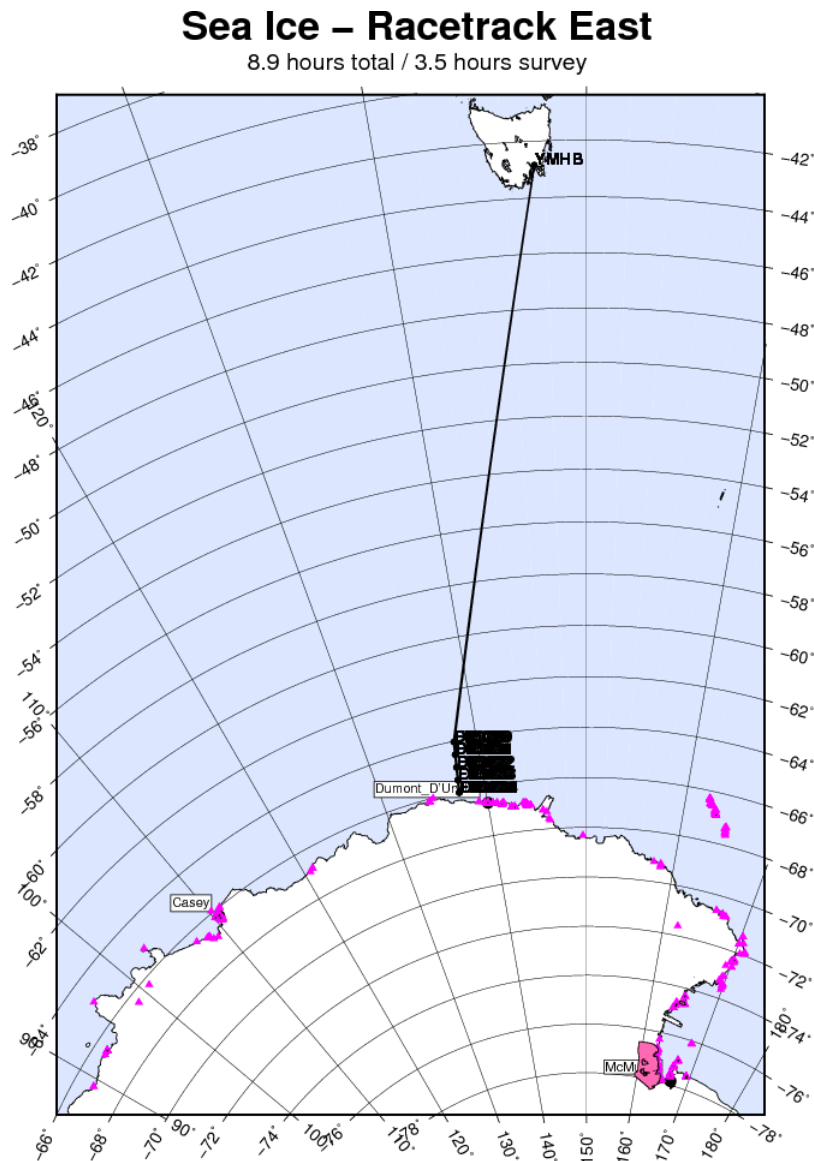
# Sea Ice – Racetrack East

This mission is designed to fly three circuits of a “racetrack” pattern along a low-latency ICESat-2 ground track. The two legs of the racetrack are the “D” and “F” (strong TEP beams) of the selected RGT. The three circuits are designed to widen the composite swath of each leg, to improve the changes of coincident OIB and IS-2 measurements in the presence of ice drift. Appendix D has more details on how this composite swath is designed in the presence of differing wind scenarios.

**Flight Priority:** high

**ICESat-2 Tracks:** TBD

**Remaining Design Issues:** must be redesigned daily according to IS2 tracks



# Sea Ice – Racetrack Central

This mission is designed to fly three circuits of a “racetrack” pattern along a low-latency ICESat-2 ground track. The two legs of the racetrack are the “D” and “F” (strong TEP beams) of the selected RGT. The three circuits are designed to widen the composite swath of each leg, to improve the changes of coincident OIB and IS-2 measurements in the presence of ice drift. Appendix D has more details on how this composite swath is designed in the presence of differing wind scenarios.

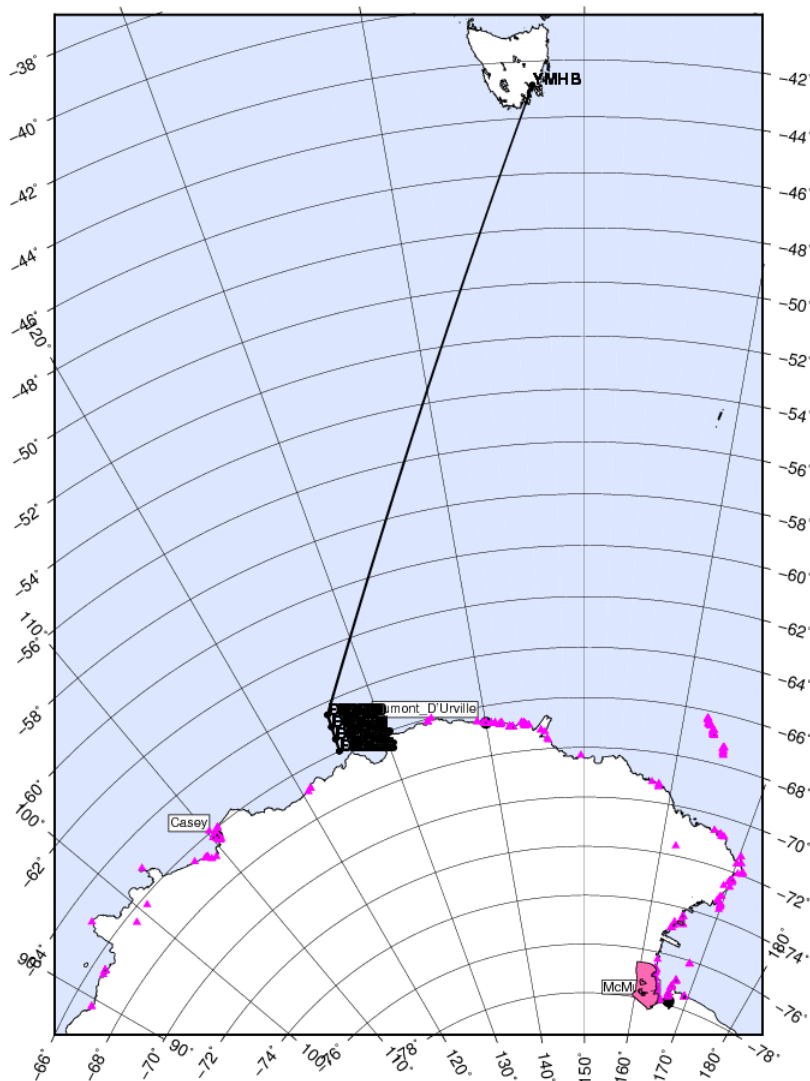
**Flight Priority:** high

**ICESat-2 Tracks:** TBD

**Remaining Design Issues:** must be redesigned daily according to IS2 tracks

## Sea Ice – Racetrack Central

9.0 hours total / 2.7 hours survey



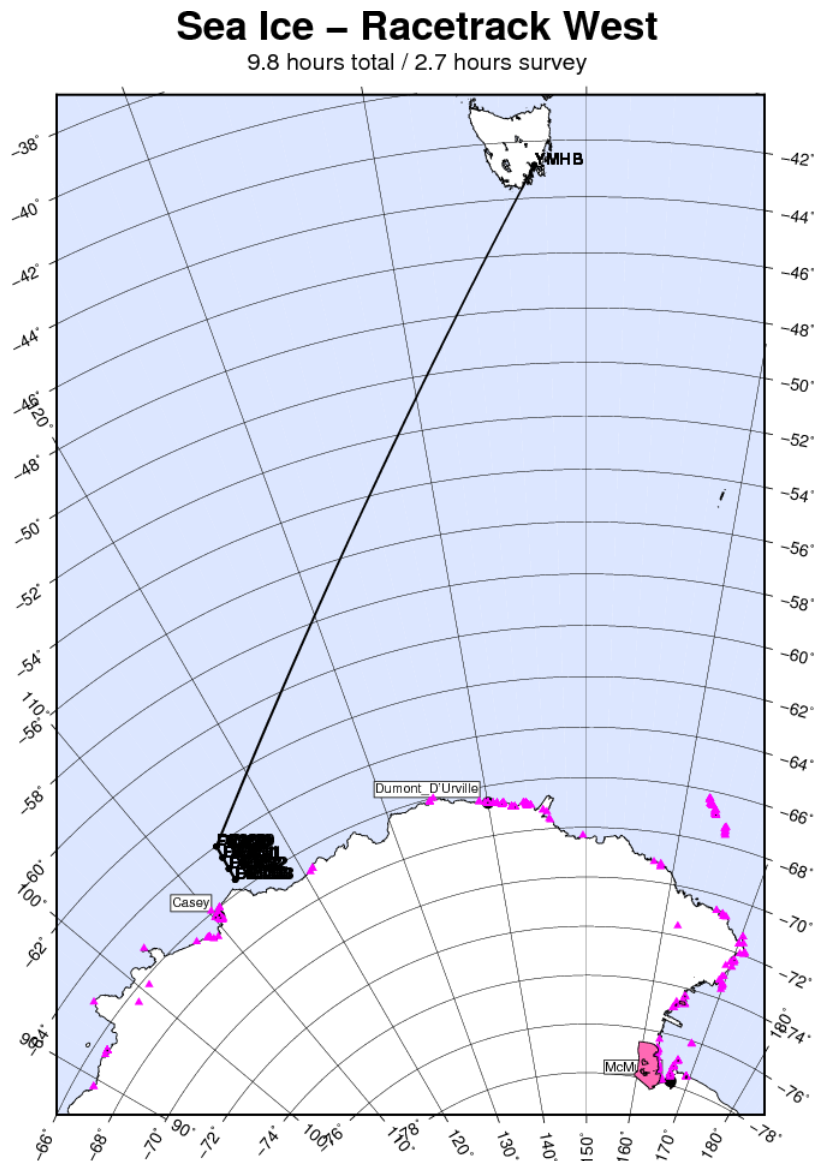
# Sea Ice – Racetrack West

This mission is designed to fly three circuits of a “racetrack” pattern along a low-latency ICESat-2 ground track. The two legs of the racetrack are the “D” and “F” (strong TEP beams) of the selected RGT. The three circuits are designed to widen the composite swath of each leg, to improve the changes of coincident OIB and IS-2 measurements in the presence of ice drift. Appendix D has more details on how this composite swath is designed in the presence of differing wind scenarios.

**Flight Priority:** medium

**ICESat-2 Tracks:** TBD

**Remaining Design Issues:** must be redesigned daily according to IS2 tracks



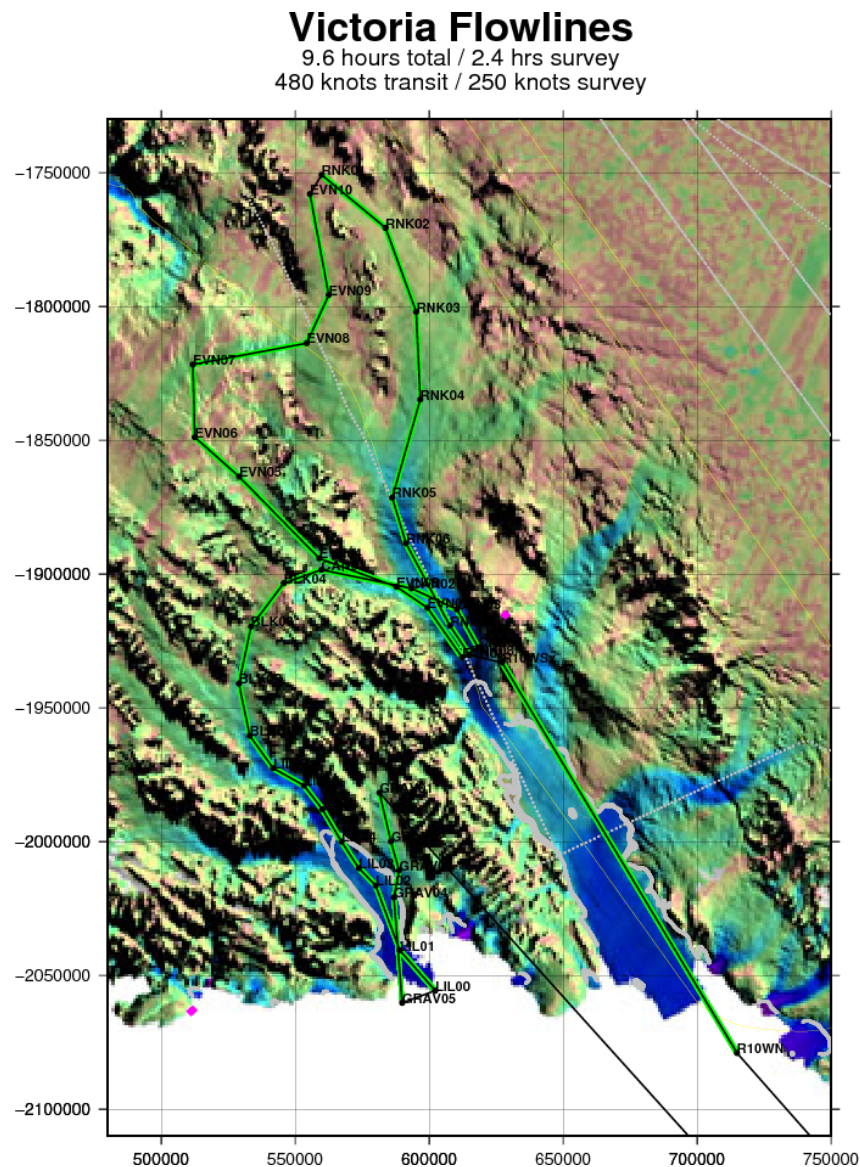
# Land Ice – Victoria Flowlines

This mission is designed to survey a series of glacier flowlines in Victoria Land. The glaciers include Lilie, Black, Canham, Rennick, and additional flowlines draining Evans Neve. Most of these areas are unmapped in terms of bedrock geometry, although we do repeat small sections of 2013 and 2017 OIB flights in the area. We also extend the Rennick 01/02 grid on the exit leg of this mission, in order to help fill a gap in bedrock measurements, which corresponds to an area of thinning identified by ICESat-1.

**Flight Priority:** medium

**ICESat-2 Tracks:** none

**Remaining Design Issues:** none



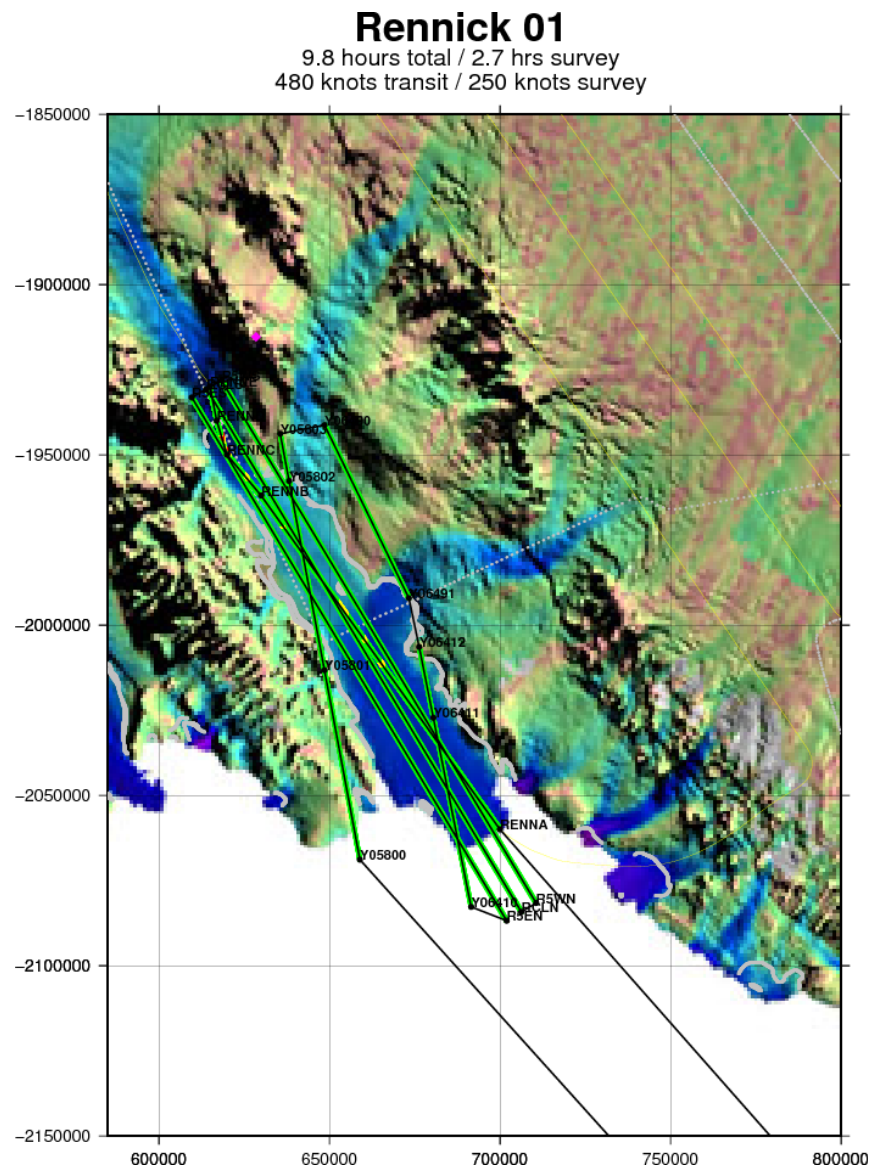
# Land Ice – Rennick 01

This mission is designed to survey the floating ice shelf of Rennick Glacier, along with the lower portion of the glacier itself, on a 5 km grid. The grid in this mission is supplemented by additional lines in the Rennick 02 flight. In addition, we fly a repeat of our 2013 Rennick centerline, primarily on the shelf. We also fly tie lines across the grid on a pair of ICESat-2 lines.

**Flight Priority:** high

**ICESat-2 Tracks:** Y0580,Y0641,Y0649

**Remaining Design Issues:** none



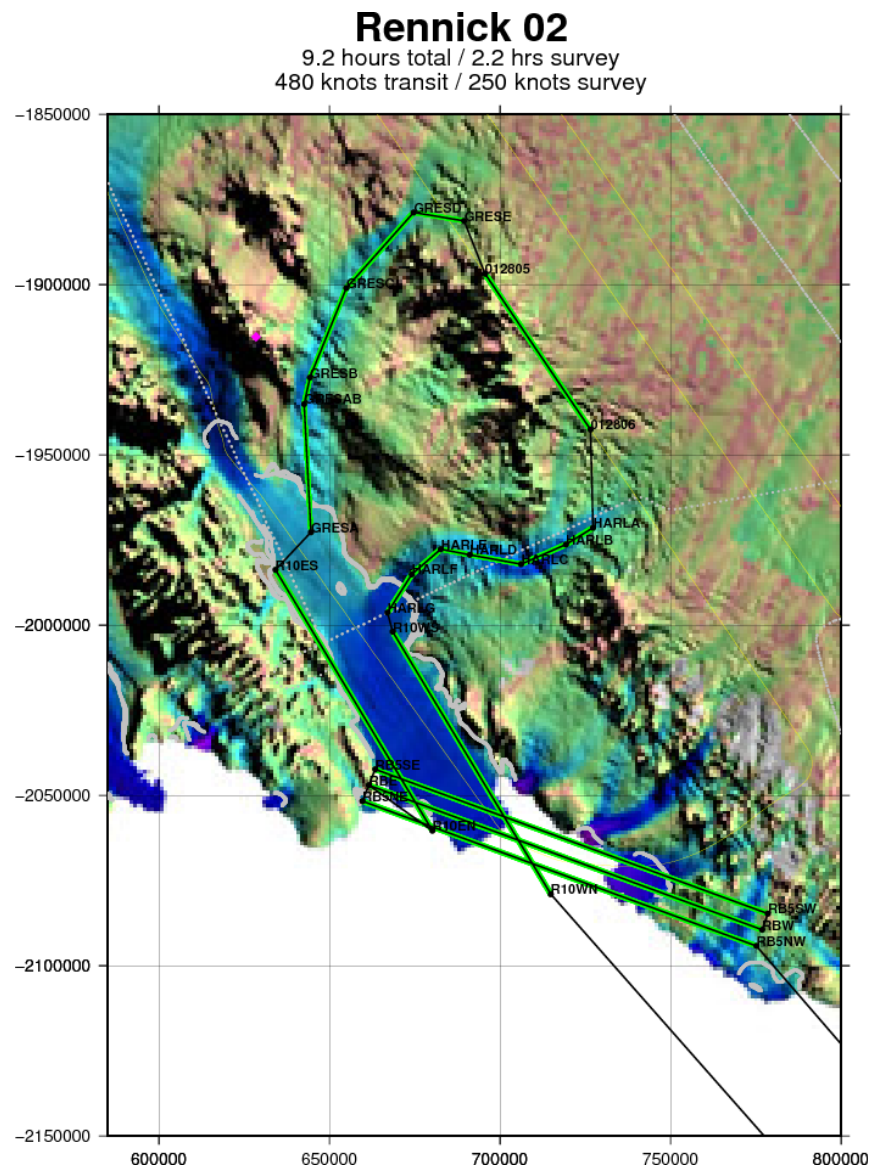
# Land Ice – Rennick 02

This mission is designed to survey the centerlines of the Gressitt and Harlin Glaciers, both tributaries of the Rennick Glacier's ice shelf. These two centerlines also help fill a gap in bedrock measurements, which corresponds to an area of thinning identified by ICESat-1. In addition, it adds to the Rennick 01 ice shelf grid by extending it 5 km more to each side. Finally it supplements the seaward portion of the Rennick 01 survey with a different 5 km grid, which also extends to the floating portions of the Suvorov and Pryor Glaciers.

**Flight Priority:** medium

**ICESat-2 Tracks:** none

**Remaining Design Issues:** none



# Land Ice – George V Gap 01

This mission extends all-sensor coverage of this portion of Victoria and Wilkes Land, with the purpose of filling a measurement gap between previous ICECAP and BAS surveys in the region.

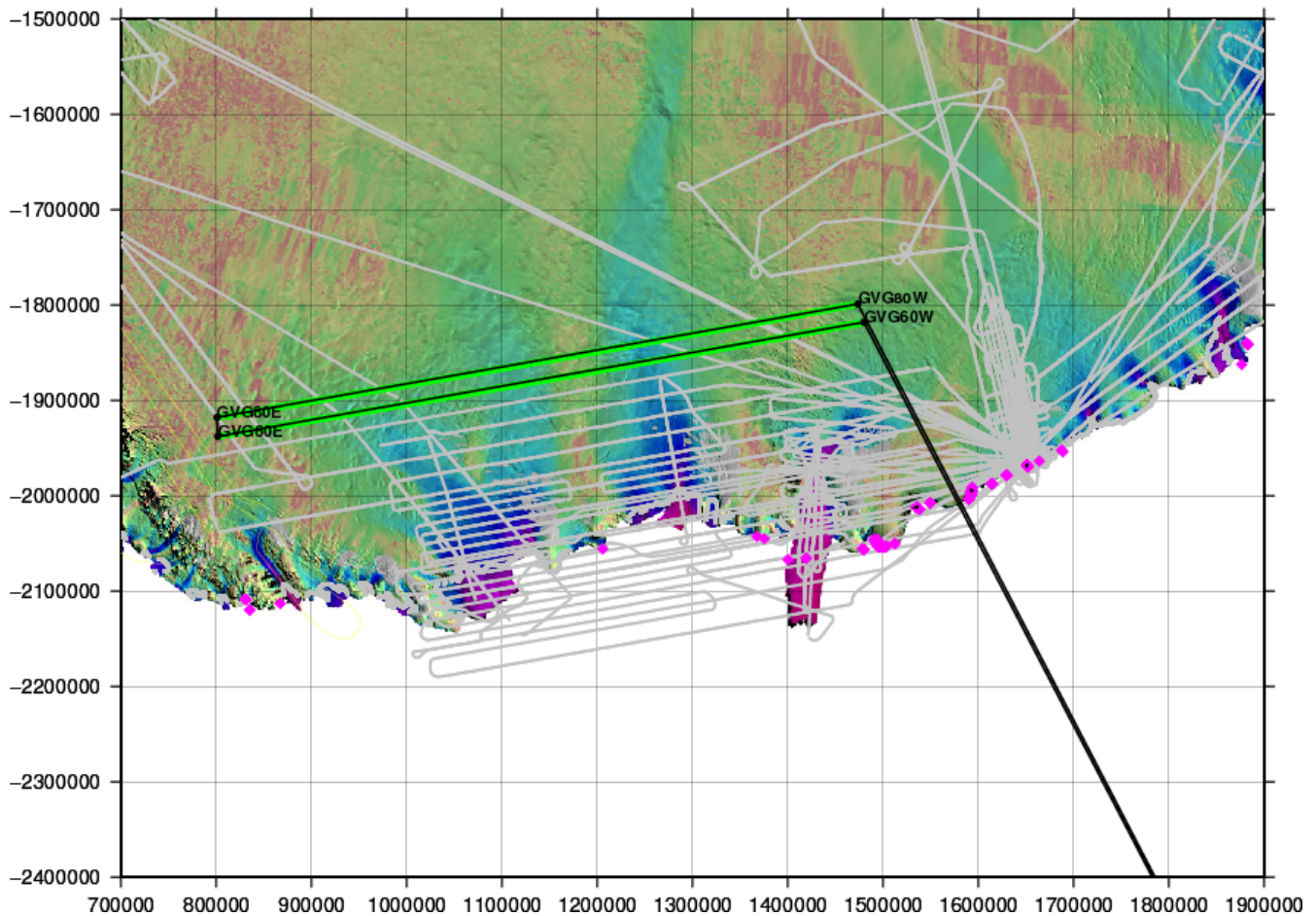
**Flight Priority:** medium

**ICESat-2 Tracks:** none

**Remaining Design Issues:** none

## George V Gap 01

9.6 hours total / 3.1 hrs survey  
480 knots transit / 250 knots survey



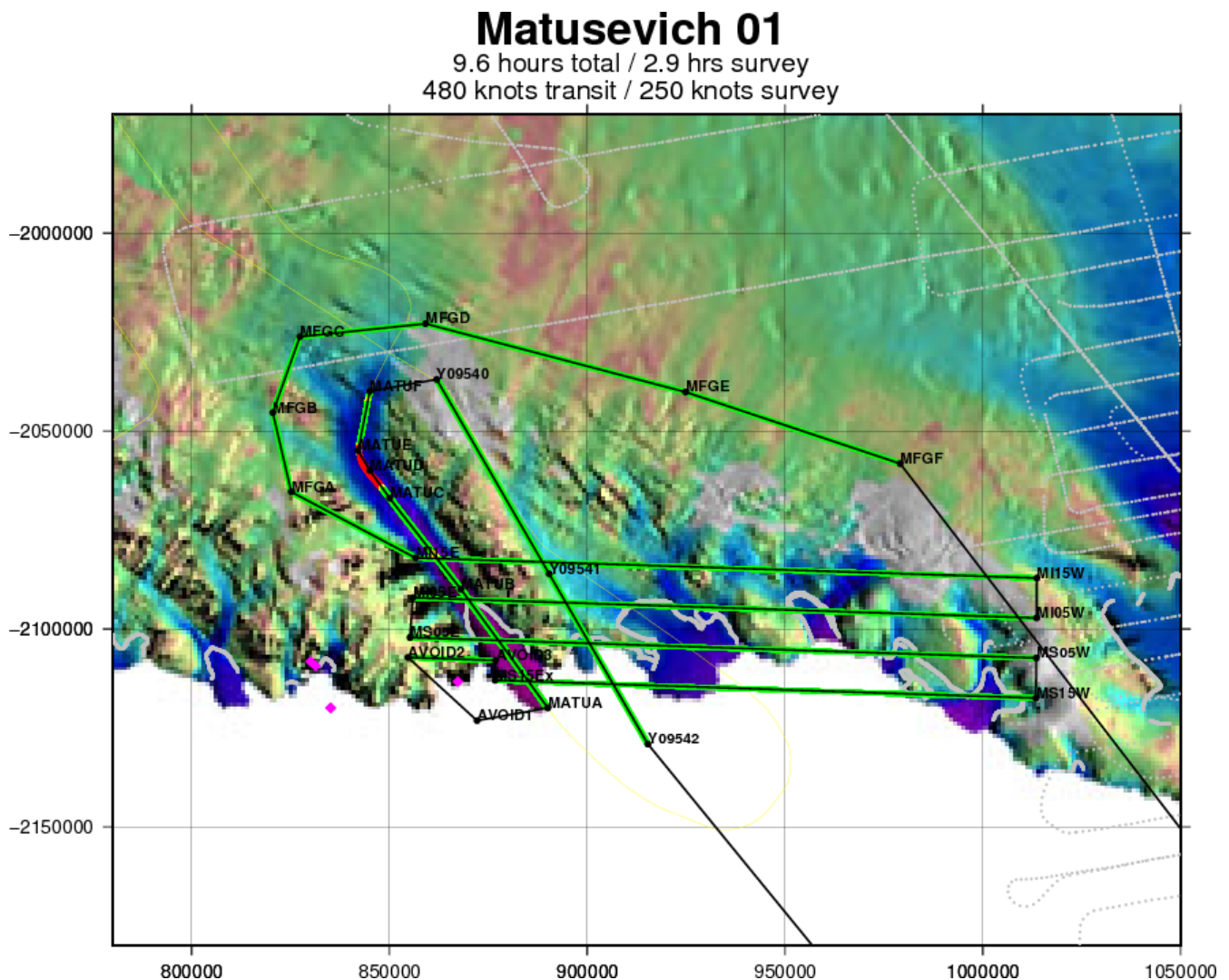
# Land Ice – Matusевич 01

This mission is designed to survey the lower Matusевич Glacier and its ice shelf, plus adjoining Lauritzen Bay and the Slava Ice Shelf, on a 10 km grid. We also fly a flux gate upstream of the area. In addition, we fly an ICESat-2 track as a tie line for the ice shelf grid, and we also re-fly the 2013 OIB centerline of the Matusевич Glacier and shelf, which can serve as an additional tie line since its lower portion is very straight. The companion Matusевич 02 mission improves the grid density to 5 km.

**Flight Priority:** high

**ICESat-2 Tracks:** Y0954

**Remaining Design Issues:** none



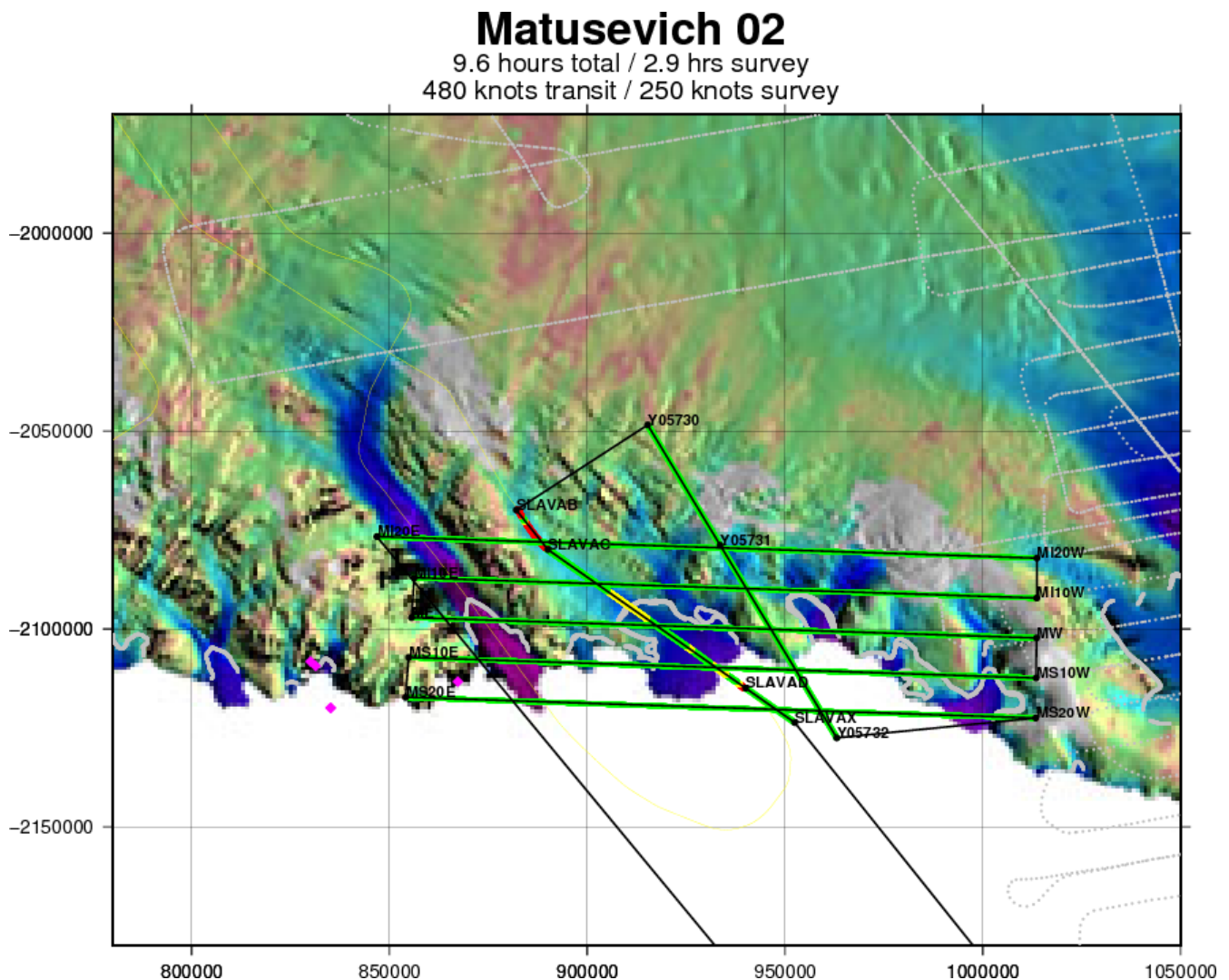
# Land Ice – Matusevich 02

This mission is designed to survey the lower Matusevich Glacier and its ice shelf, plus adjoining Lauritzen Bay and the Slava Ice Shelf, on a 10 km grid. In addition, we fly an ICESat-2 track as a tie line for the ice shelf grid, and we also reflly the 2013 OIB centerline of the Slava Glacier and shelf, which can serve as an additional tie line since its lower portion is very straight. The companion Matusevich 01 mission improves the grid density to 5 km.

**Flight Priority:** low

**ICESat-2 Tracks:** Y0573

**Remaining Design Issues:** none



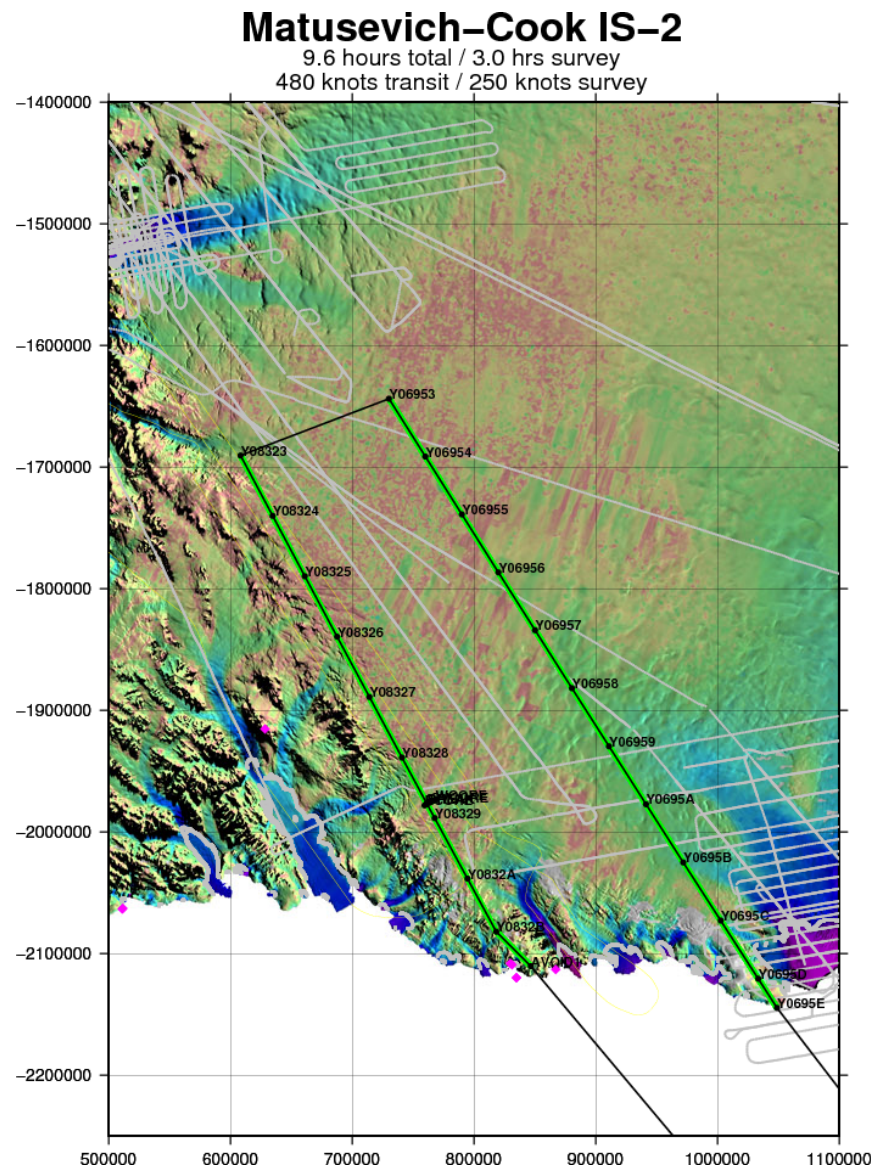
# Land Ice – Matusevich-Cook IS-2

This mission is designed to fly a pair of ICESat-2 tracks on either side of the dynamic ice feeding the Matusevich and Slava Glaciers. This region shows large discrepancies between MERRA-2 and RACMO accumulations. We also overfly a firn core (GV7). We specifically avoid fast flow regions with this flight, in order to maximize our chances of observing smooth firn stratigraphy. Finally, ICESat-2 track Y0832 also acts as a fluxgate for several glaciers draining the East Antarctic plateau into Victoria Land.

**Flight Priority:** high

**ICESat-2 Tracks:** Y0695, Y0832

**Remaining Design Issues:** none



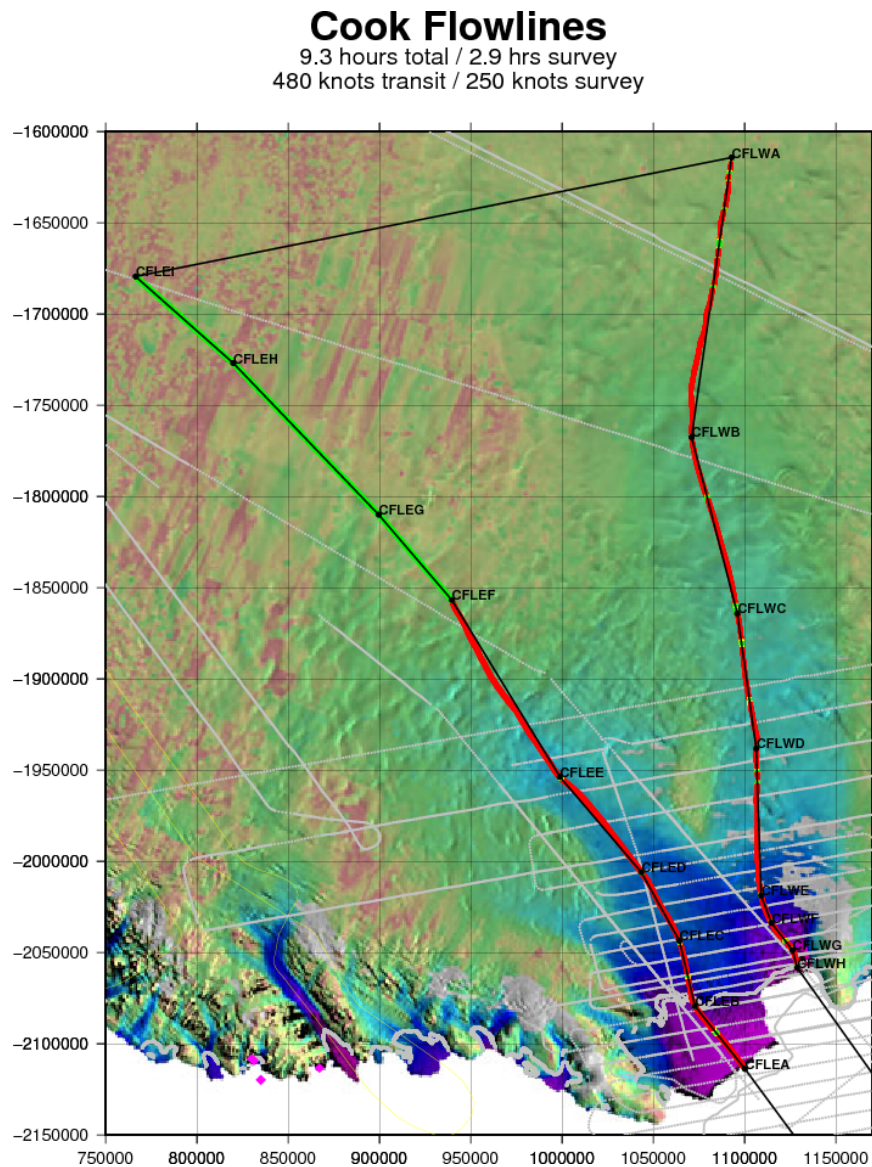
# Land Ice – Cook Flowlines

This mission is designed to survey the two main flow lines which feed the Cook Ice Shelf. The eastern flow line addresses a large over-deepening and extends all the way to the ice divide. The western flow line addresses the trunk that feeds the portion of Cook Ice Shelf which collapsed during the observation record. These lines will connect older ICECAP and BAS WISE/ISODYNE surveys, and capture along-flow features in a region that is particularly sensitive to instability.

**Flight Priority:** high

**ICESat-2 Tracks:** none

**Remaining Design Issues:** none



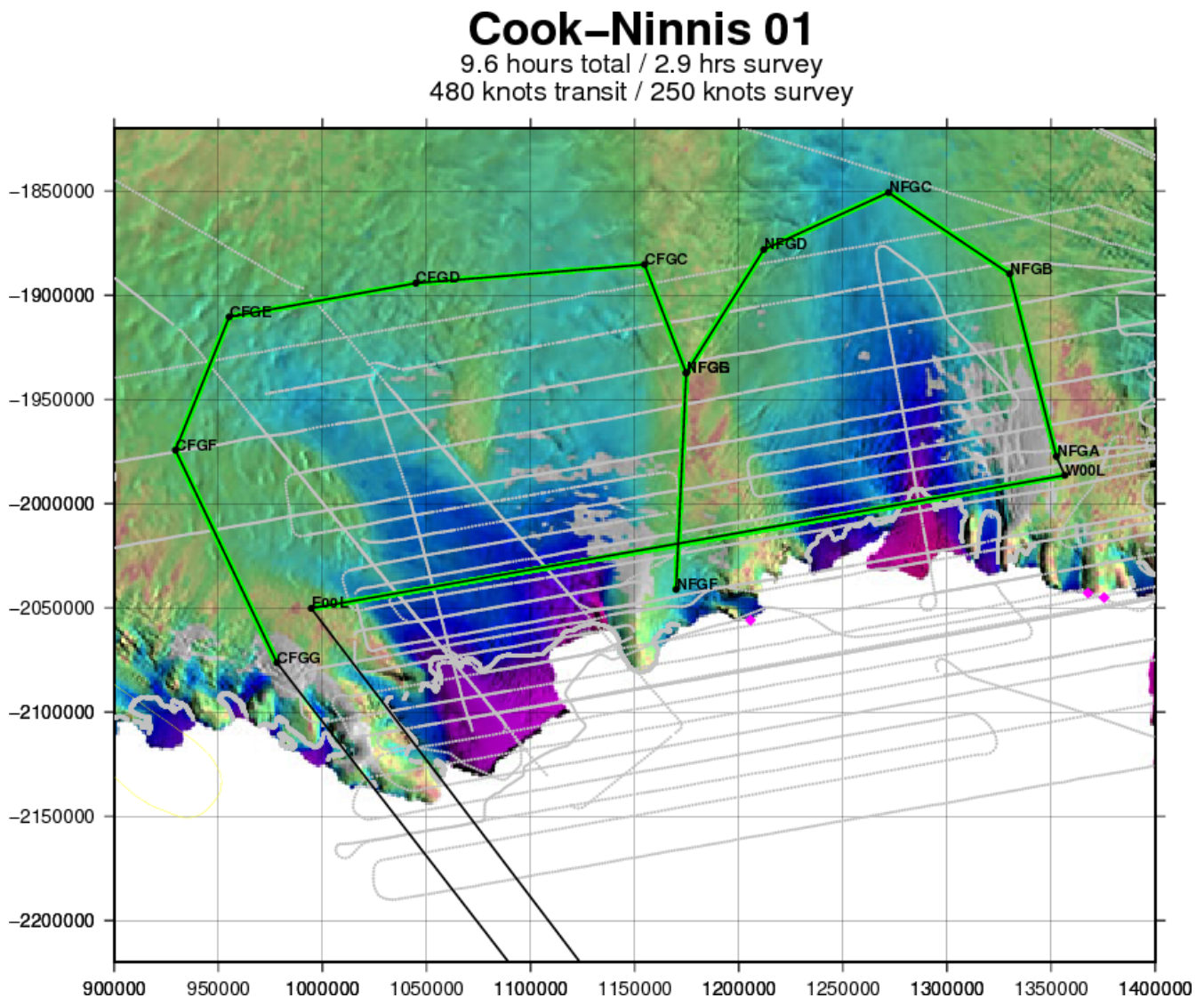
# Land Ice – Cook-Ninnis 01

This mission is designed to survey the the Cook and Ninnis Glaciers, in conjunction with the Cook-Ninnis 02-04 flights. This particular flight surveys flux gates above the two glaciers, and one coast-parallel grid line, which lies almost entirely above the grounding line. The grid is designed to supplement earlier airborne measurements collected by the ICECAP Project, with our lines falling midway between the ICECAP lines.

**Flight Priority:** high

**ICESat-2 Tracks:** none

**Remaining Design Issues:** none



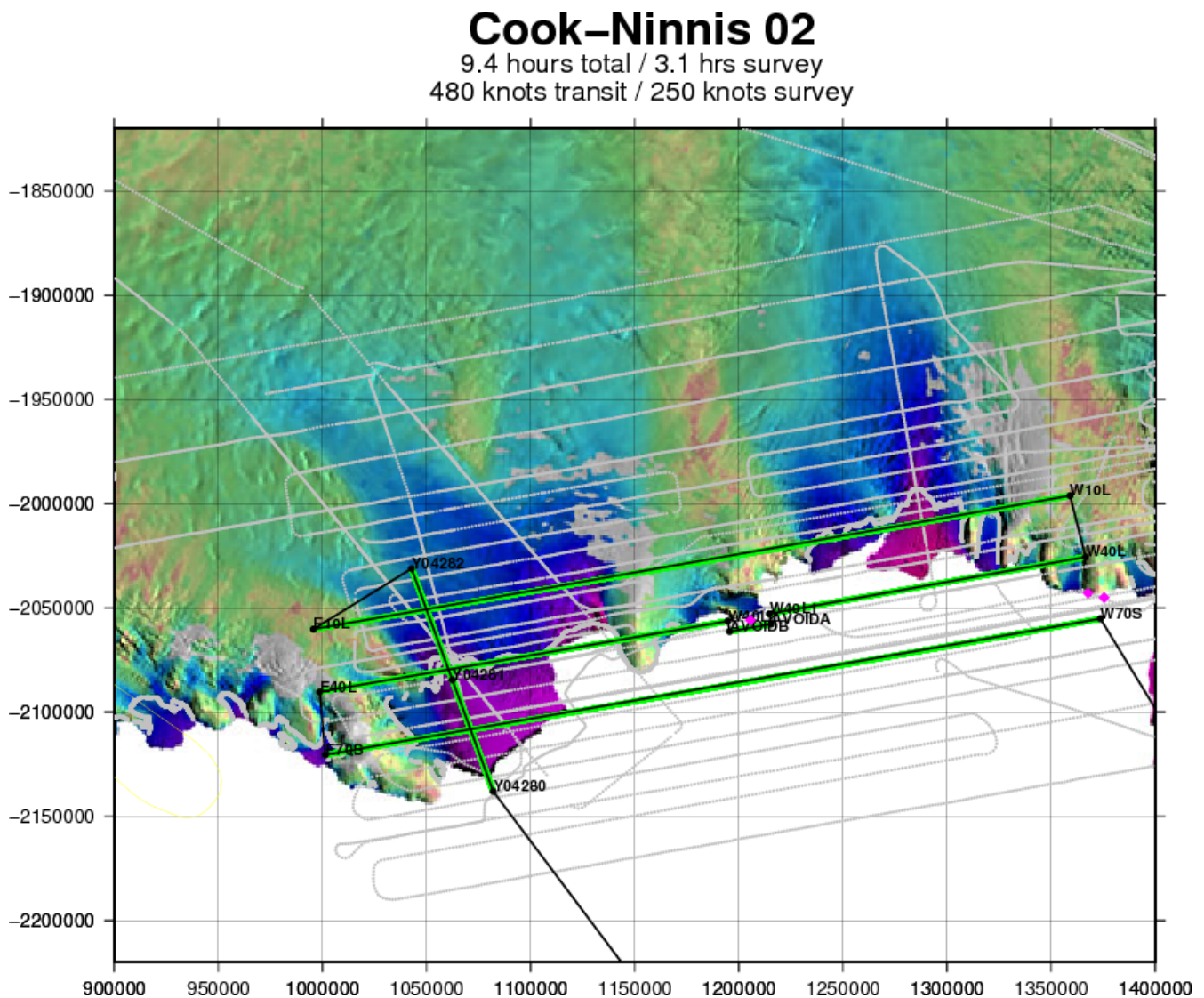
# Land Ice – Cook-Ninnis 02

This mission is designed to survey the the Cook and Ninnis Glaciers, in conjunction with the Cook-Ninnis 01 and 03-04 flights. This particular flight surveys coast-parallel grid lines spaced at 30 km. All four missions together yield a 10-km grid. We also fly a tie line along an ICESat-2 ground track. The grid is designed to supplement earlier airborne measurements collected by the ICECAP Project, with our lines falling midway between the ICECAP lines.

**Flight Priority:** high

## ICESat-2 Tracks: Y0428

**Remaining Design Issues:** none



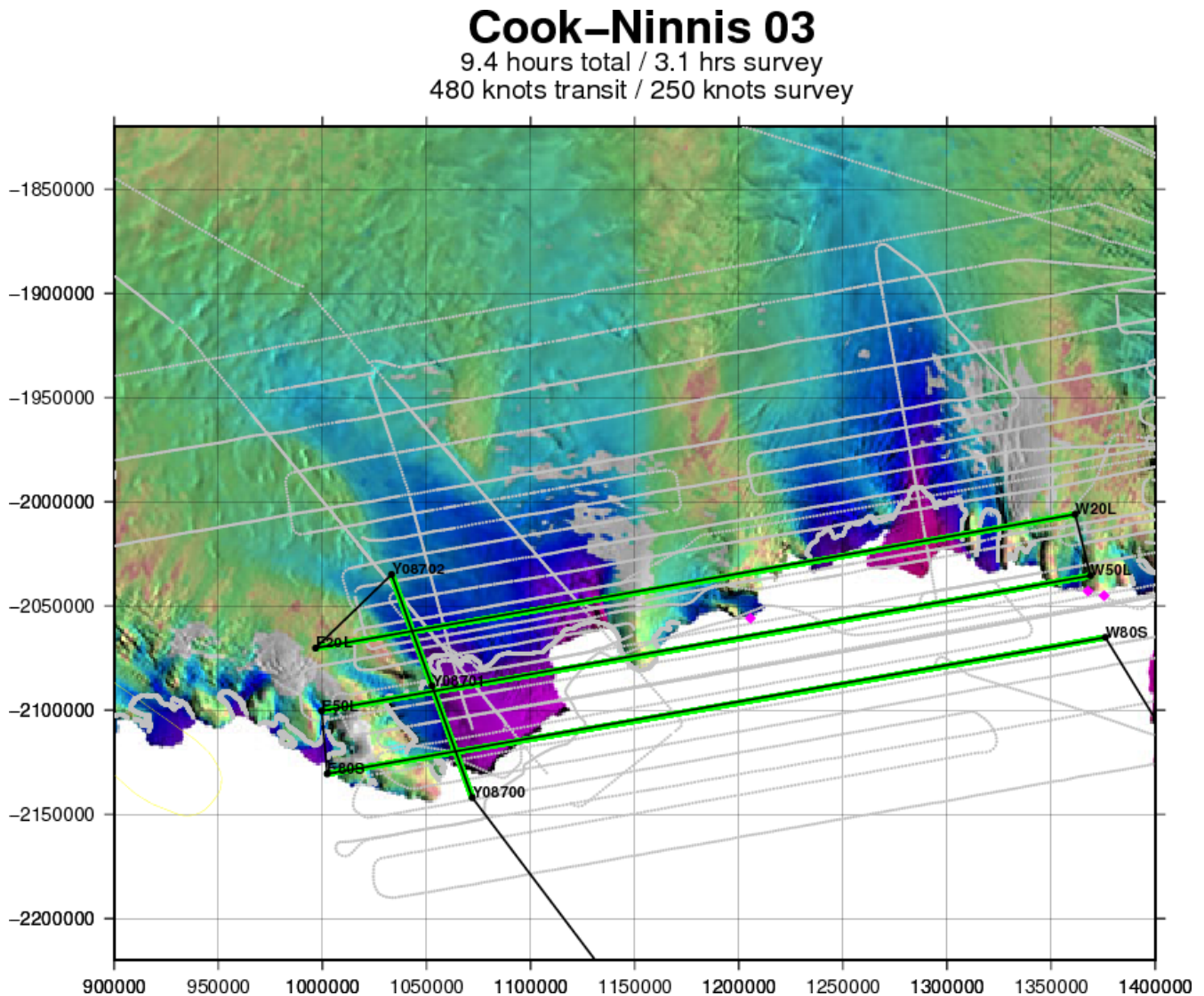
# Land Ice – Cook-Ninnis 03

This mission is designed to survey the the Cook and Ninnis Glaciers, in conjunction with the Cook-Ninnis 01-02 and 04 flights. This particular flight surveys coast-parallel grid lines spaced at 30 km. All four missions together yield a 10-km grid. We also fly a tie line along an ICESat-2 ground track. The grid is designed to supplement earlier airborne measurements collected by the ICECAP Project, with our lines falling midway between the ICECAP lines.

**Flight Priority:** low

## ICESat-2 Tracks: Y0870

**Remaining Design Issues:** none



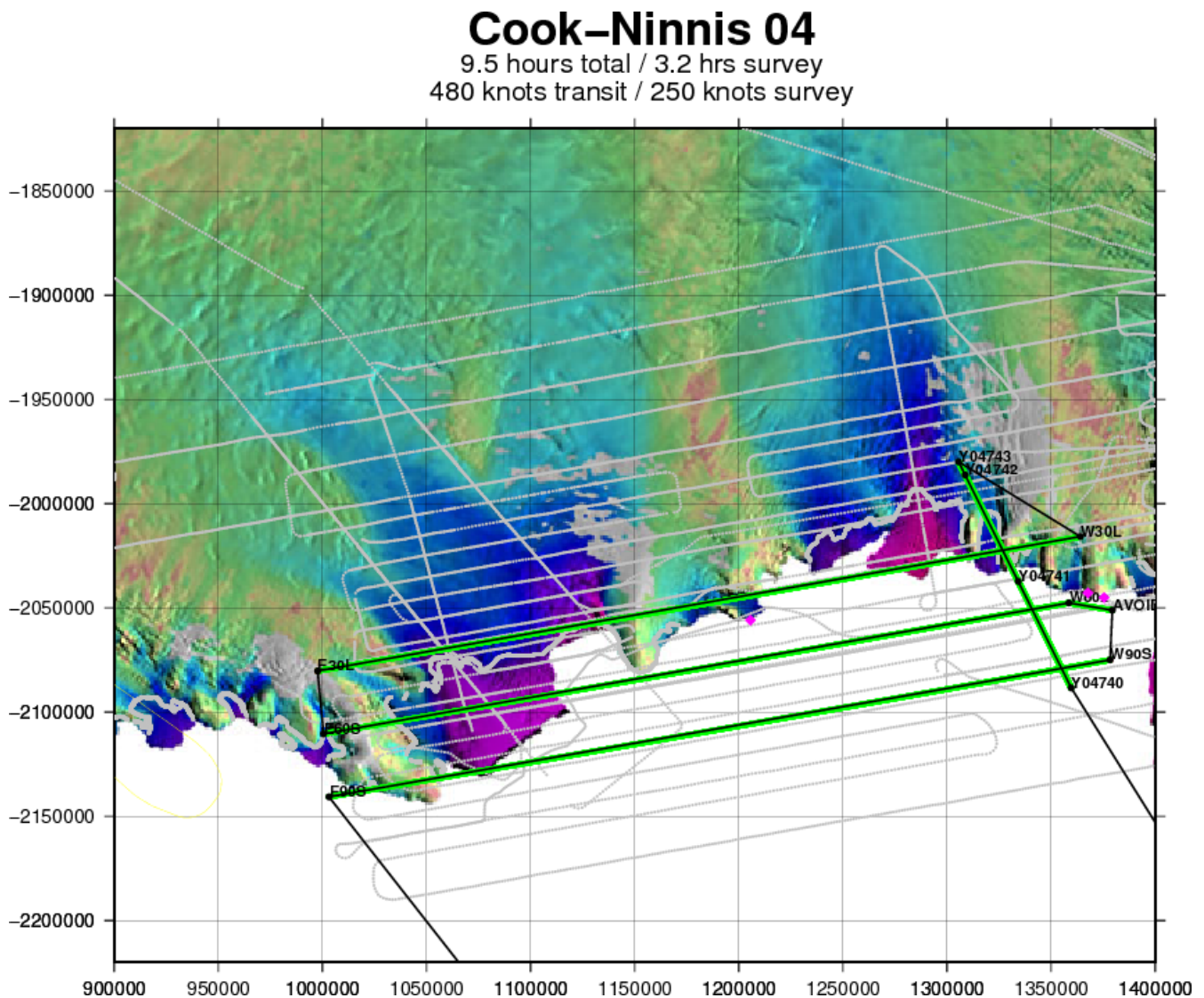
# Land Ice – Cook-Ninnis 04

This mission is designed to survey the the Cook and Ninnis Glaciers, in conjunction with the Cook-Ninnis 01-03 flights. This particular flight surveys coast-parallel grid lines spaced at 30 km. All four missions together yield a 10-km grid. We also fly a tie line along an ICESat-2 ground track. The grid is designed to supplement earlier airborne measurements collected by the ICECAP Project, with our lines falling midway between the ICECAP lines.

**Flight Priority:** medium

**ICESat-2 Tracks:** Y0474

**Remaining Design Issues:** none



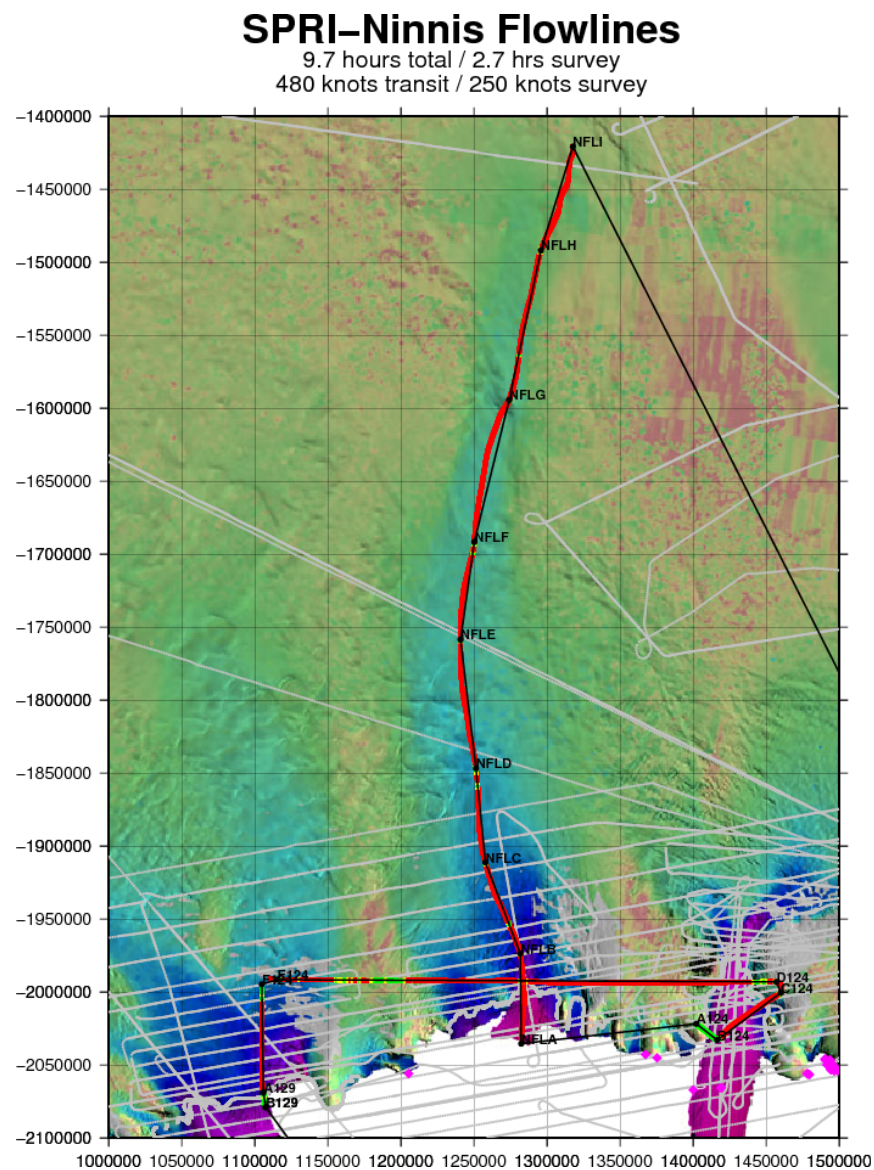
# Land Ice – SPRI-Ninnis Flowlines

This mission is designed to survey a central flow line of Ninnis Glacier. This portion of the George V Coast is potentially unstable, since the ice can retreat into the Wilkes Subglacial Basin. Bed topography in the upper portion of this line is constrained by the coarse SPRI grid, so this mission will also help to further constrain the bed topography in the region. We also refly portions of two historical 1967-1979 SPRI-TUD-NSF flights, 124 and 129, on the George V Coast. We specifically target the portions of these flights which sounded the Cook, Ninnis and Mertz Ice Shelves, for the purpose of measuring multidecadal change in their thickness.

**Flight Priority:** medium

**ICESat-2 Tracks:** none

**Remaining Design Issues:** none



# Land Ice – ASUMA Traverse

This mission is designed to fly the ASUMA traverse route, primarily for the purpose of tracking snow accumulation across the traverse route, which itself collected snow accumulation information.

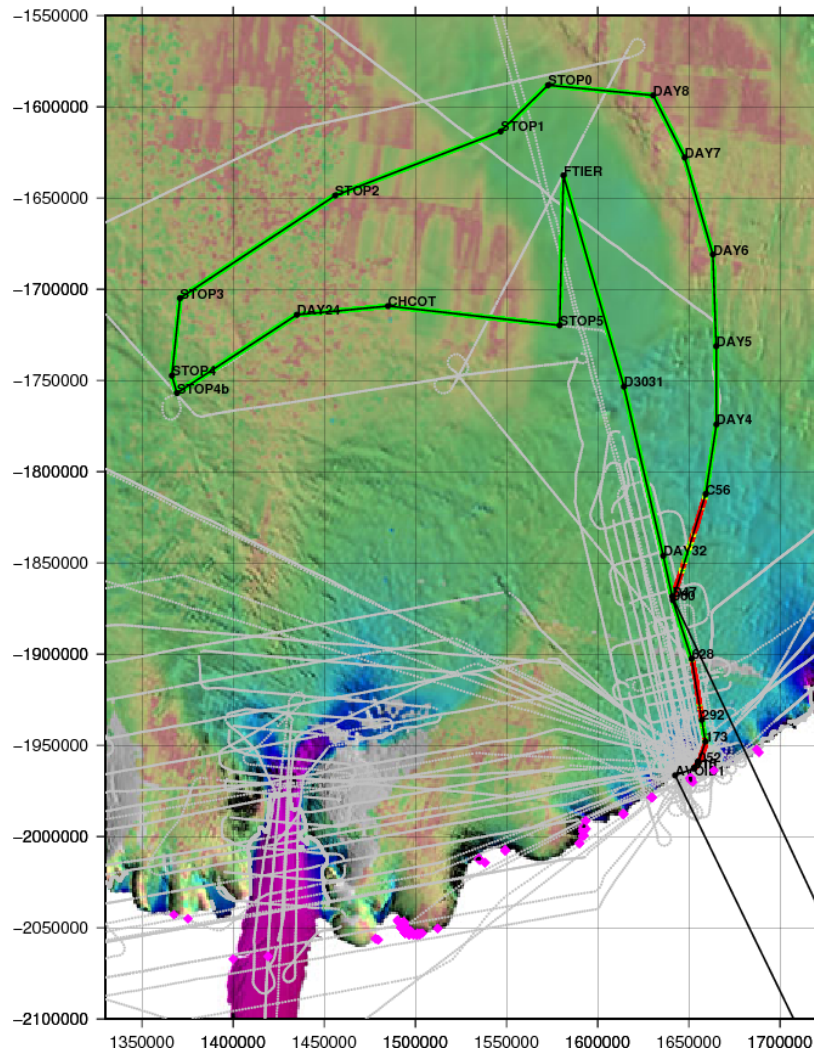
**Flight Priority:** medium

**ICESat-2 Tracks:** none

**Remaining Design Issues:** none

## ASUMA Traverse

9.2 hours total / 3.1 hrs survey  
480 knots transit / 250 knots survey



# Land Ice – Adelie-Clarie Gap 01

This mission is designed to fill gaps in bedrock topography along the Adelie and Clarie Coasts, on a 10 km grid. The gaps are between previous ICECAP surveys in the region.

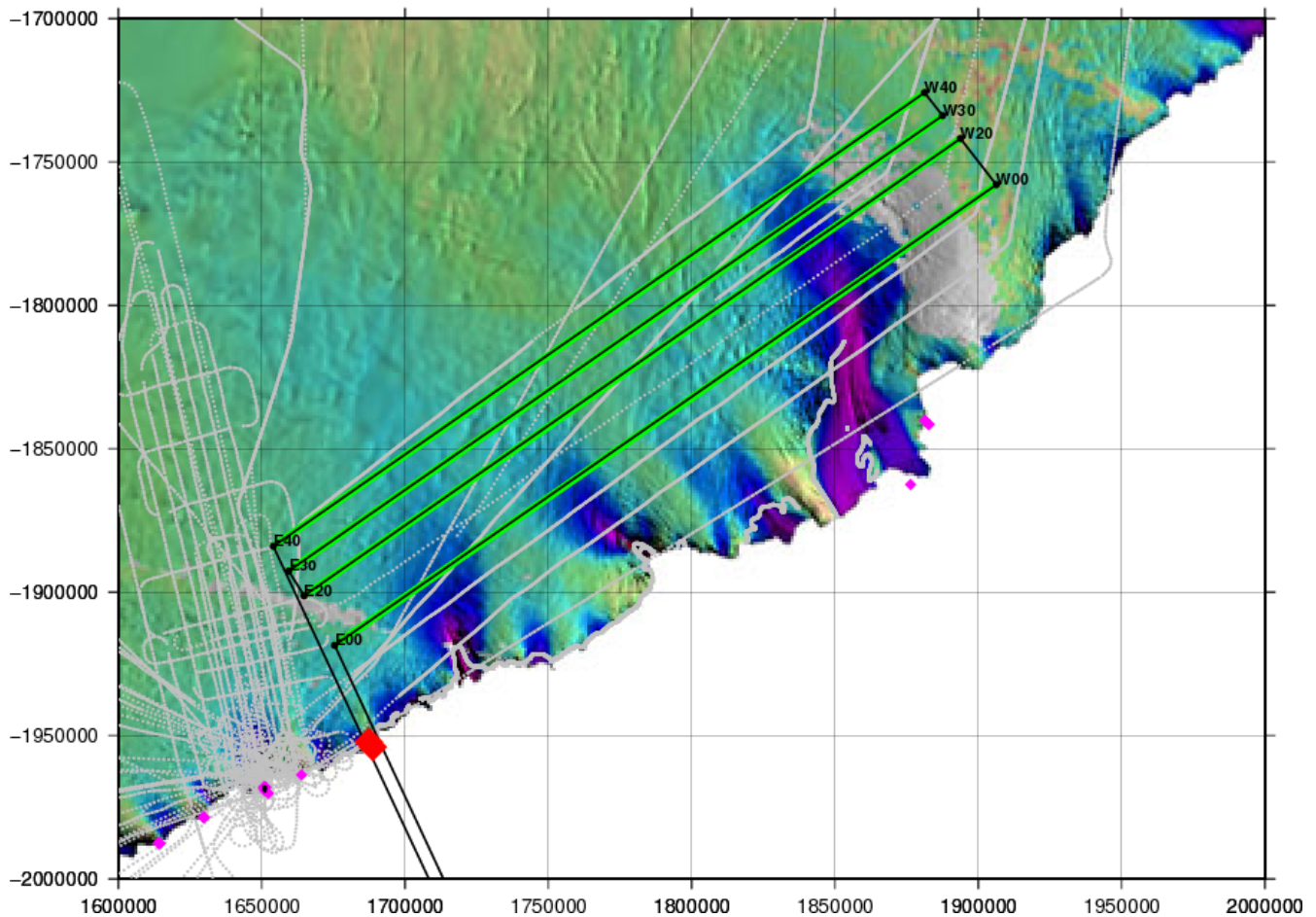
**Flight Priority:** low

**ICESat-2 Tracks:** none

**Remaining Design Issues:** none

## Adelie–Clarie Gap 01

8.9 hours total / 2.8 hrs survey  
480 knots transit / 250 knots survey



# Land Ice – Adelie-Clarie Gap 02

This mission is designed to fill gaps in bedrock topography inland of the Adelie and Clarie Coasts, on a 20 km grid. The gaps are primarily above previous ICECAP surveys in the region.

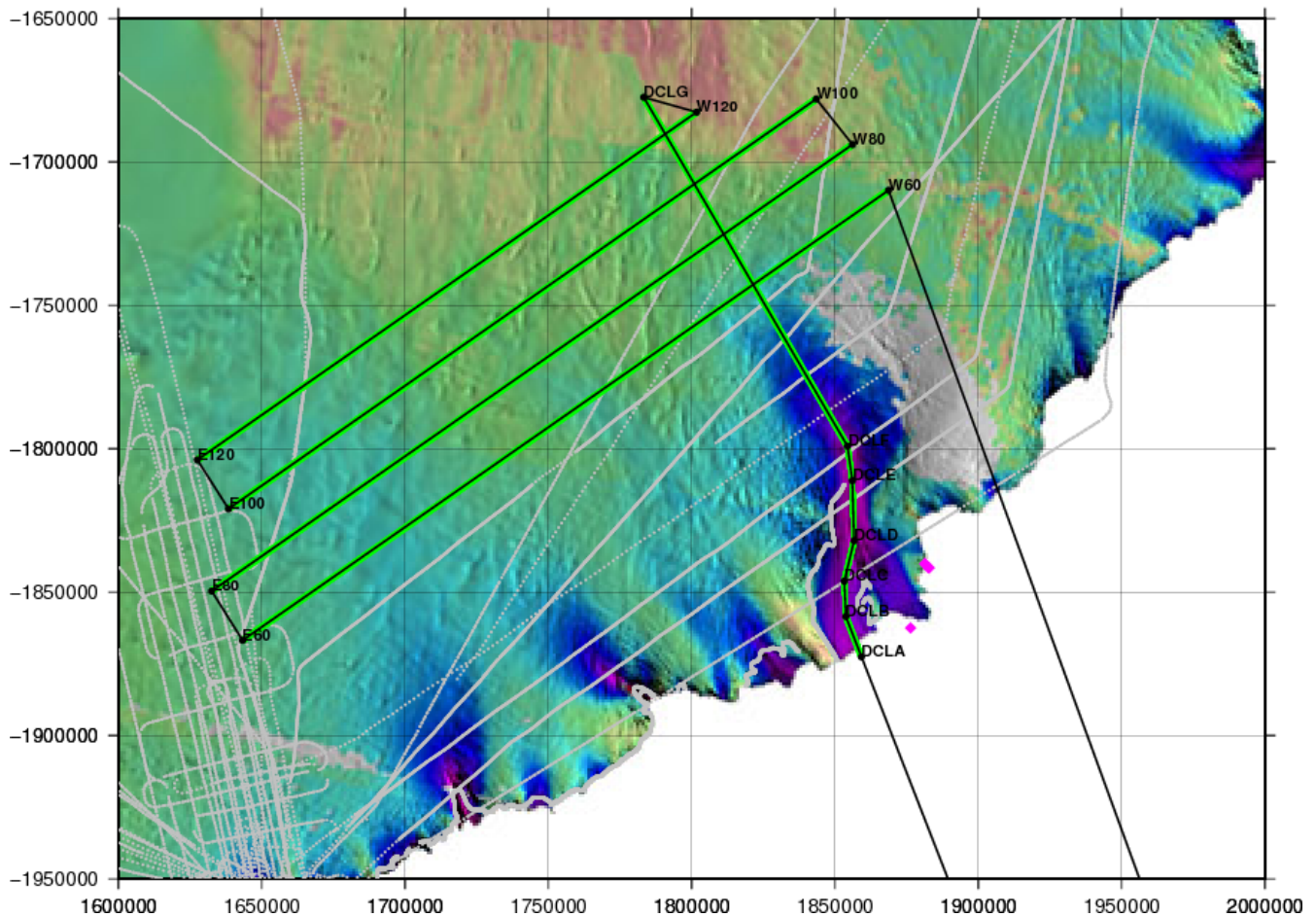
**Flight Priority:** medium

**ICESat-2 Tracks:** none

**Remaining Design Issues:** none

## Adelie-Clarie Gap 02

9.4 hours total / 3.2 hrs survey  
480 knots transit / 250 knots survey



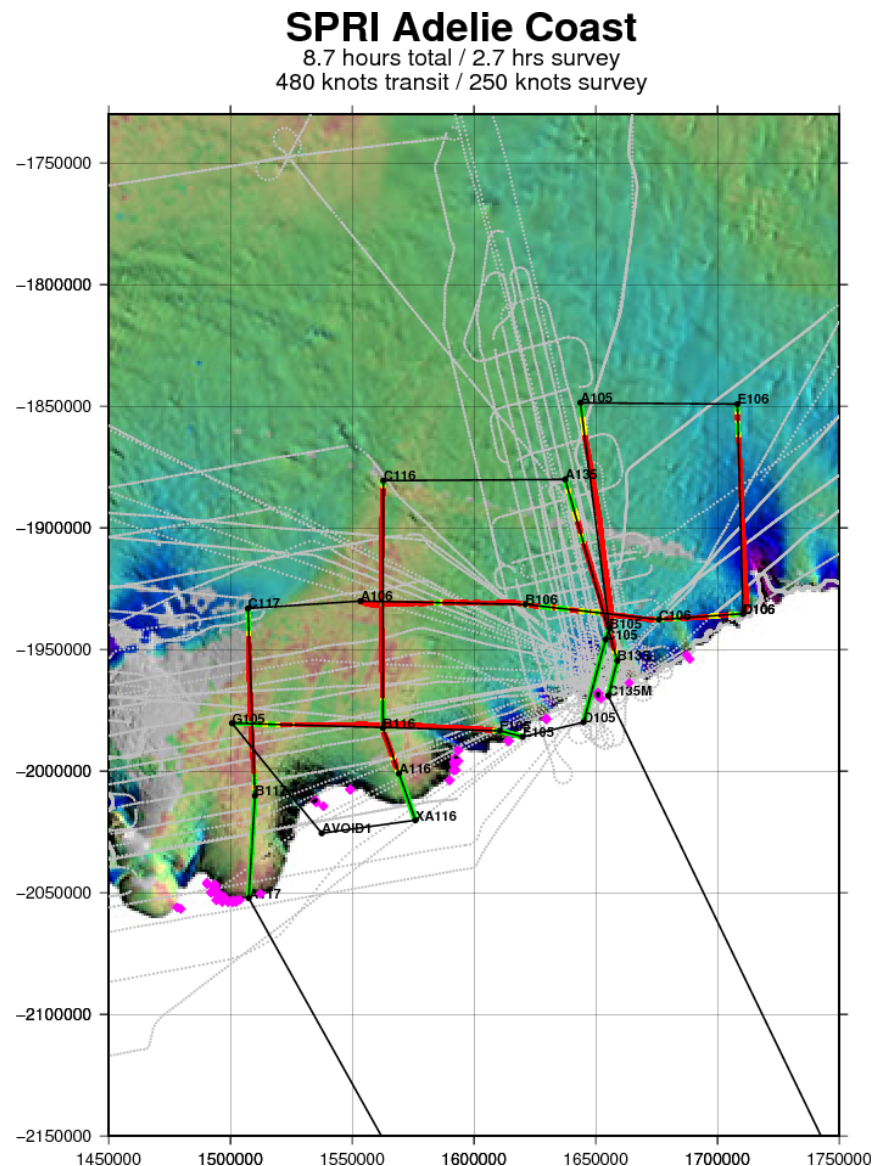
# Land Ice – SPRI Adelie Coast

This mission is designed to re-fly portions of historical 1967-1979 SPRI-TUD-NSF flights 105, 106, 116, 117 and 135 on the Adelie V Coast. We specifically target the portions of these flights which sounded small ice shelves near the Zelee, Astrolabe, Barre, and Francais Glaciers, for the purpose of measuring multidecadal change in their thickness.

**Flight Priority:** medium

**ICESat-2 Tracks:** none

**Remaining Design Issues:** none



# Land Ice – Holmes-Frost IS-2

This mission is designed to fly a pair of ICESat-2 tracks on either side of the dynamic ice feeding Porpoise Bay. This region shows large discrepancies between MERRA-2 and RACMO accumulations. We specifically avoid fast flow regions with this flight, in order to maximize our chances of observing smooth firn stratigraphy.

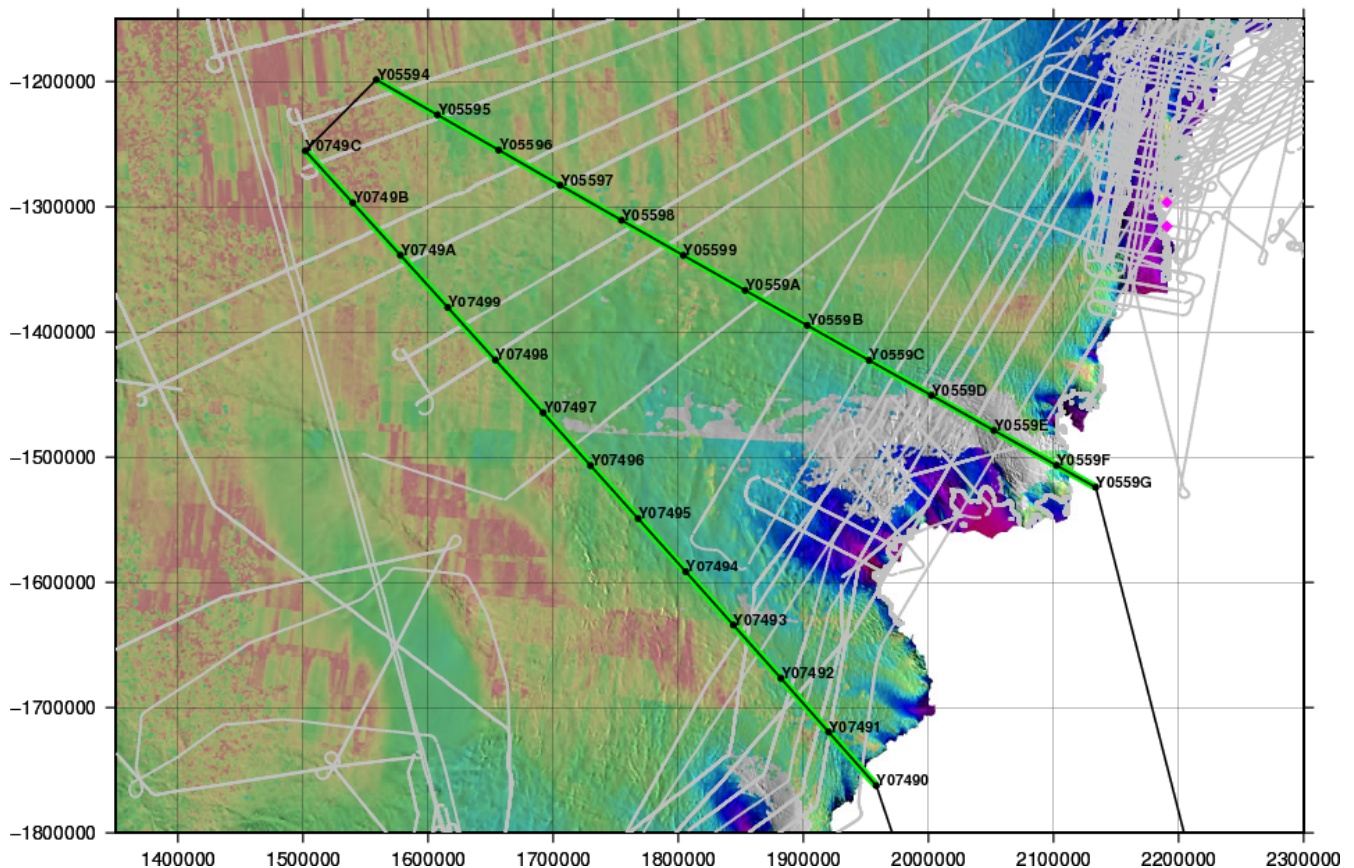
**Flight Priority:** high

**ICESat-2 Tracks:** Y0559, Y0749

**Remaining Design Issues:** none

## Holmes-Frost IS-2

9.5 hours total / 3.1 hrs survey  
480 knots transit / 250 knots survey



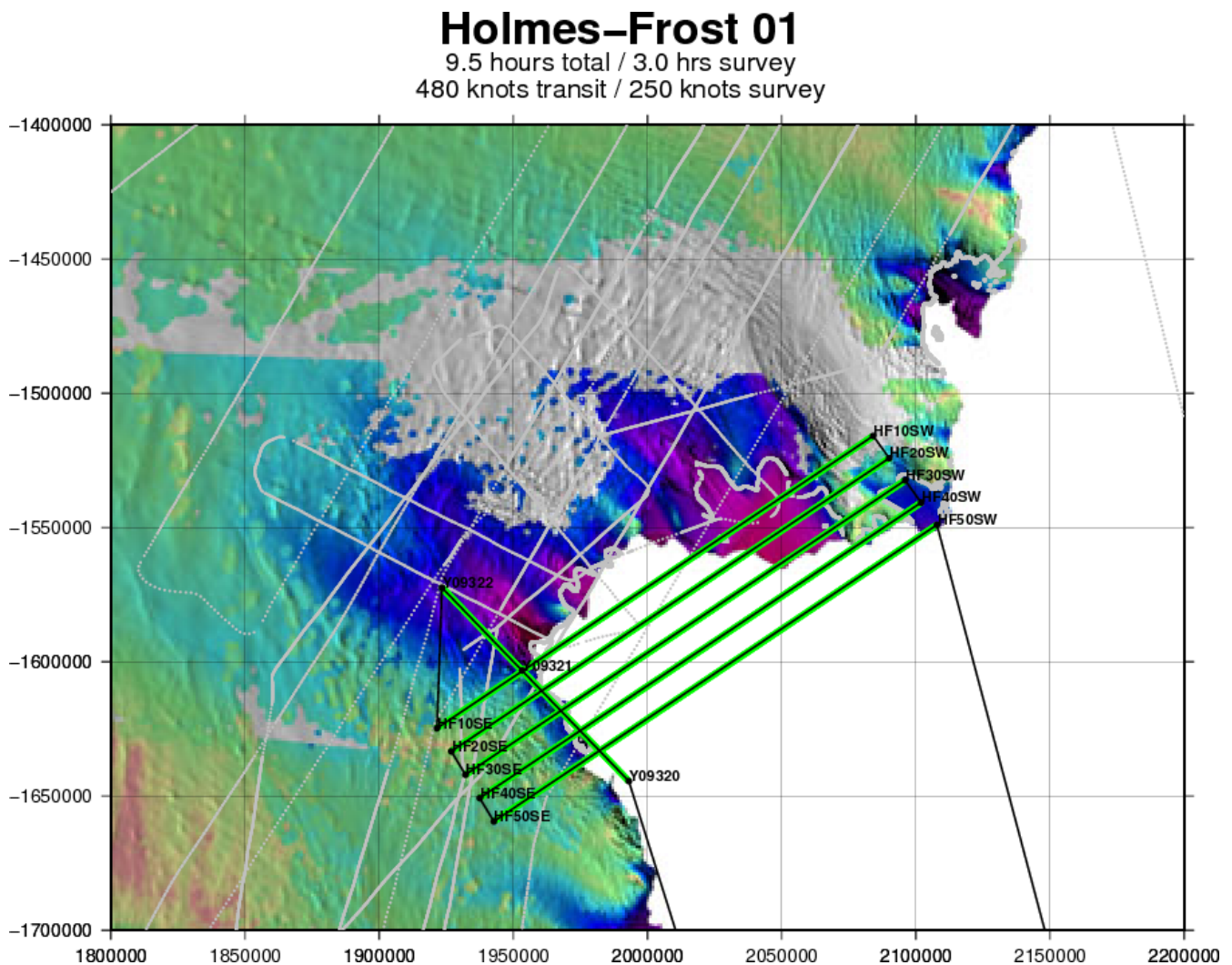
# Land Ice – Holmes-Frost 01

This mission is designed to survey the lower portions of the Holmes, De Haven and Frost Glaciers, their ice shelves, and the upper portion of Porpoise Bay beyond, all on a 10 km grid. This grid is designed to supplement earlier airborne measurements collected by the ICECAP Project. We also fly a tie line, designed along an ICESat-2 track. This grid is supplemented by the grid flown in the companion Holmes-Frost 02 mission.

**Flight Priority:** medium

**ICESat-2 Tracks:** Y0932

**Remaining Design Issues:** none



# Land Ice – Holmes-Frost 02

This mission is designed to survey the lower portions of the Holmes, De Haven and Frost Glaciers on a 10 km grid. This grid is designed to supplement earlier airborne measurements collected by the ICECAP Project. We also fly a flux gate across the upper catchment area of these glaciers, and a tie line along an ICESat-2 track. This grid is supplemented by the grid flown in the companion Holmes-Frost 01 mission.

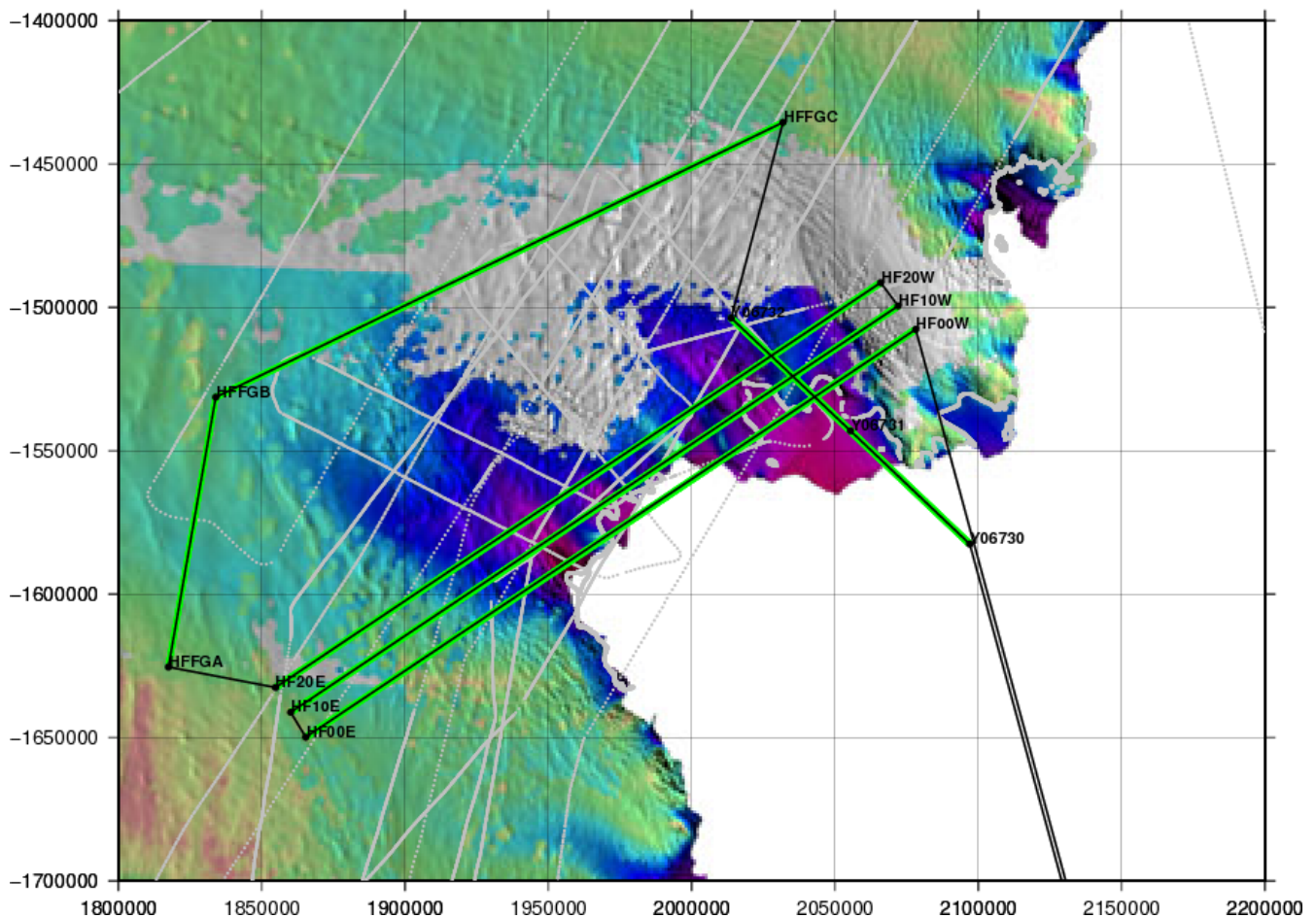
**Flight Priority:** high

**ICESat-2 Tracks:** Y0673

**Remaining Design Issues:** none

## Holmes–Frost 02

9.6 hours total / 3.0 hrs survey  
480 knots transit / 250 knots survey



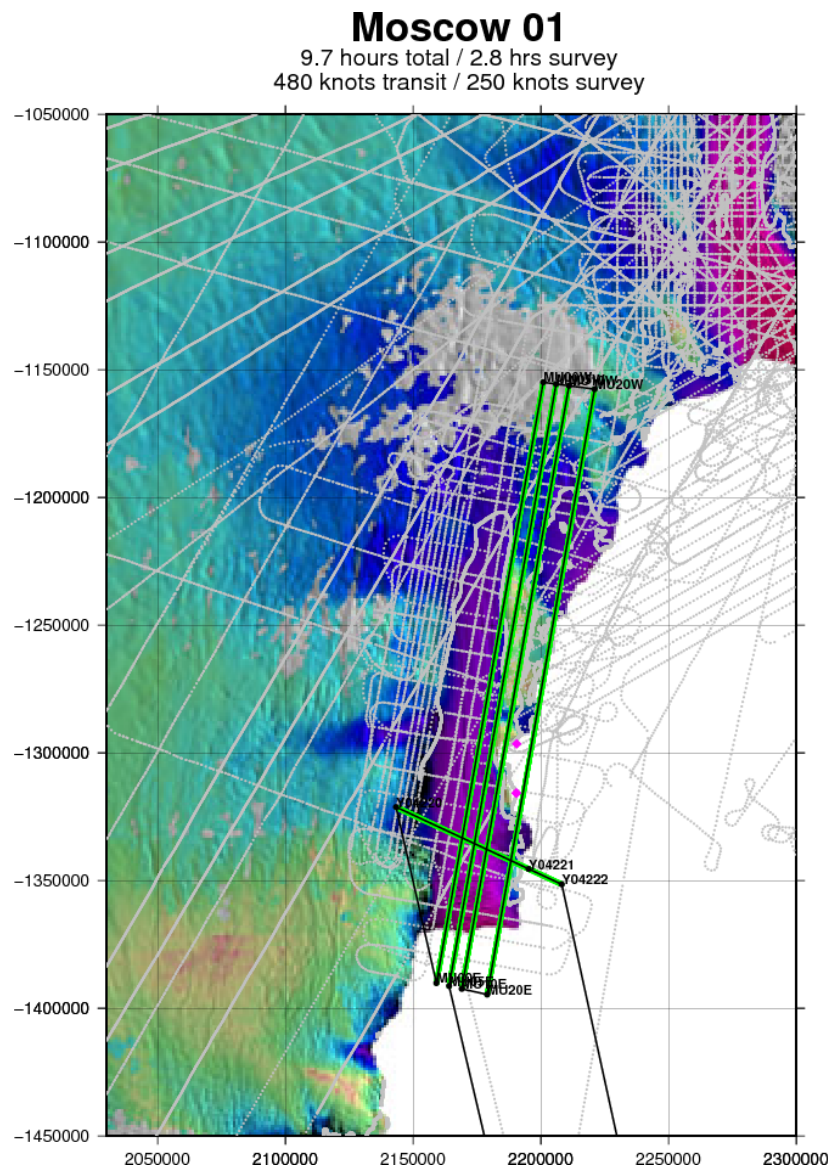
# Land Ice – Moscow 01

This mission is designed to survey portions of the Moscow University Ice Shelf and adjoining portions of the Sabrina Coast, in conjunction with the Moscow 02 flight. The grid is spaced at 5 km, once both missions are flown. We also fly a tie line on an ICESat-2 track. This grid is designed to supplement earlier airborne measurements collected by the ICECAP Project.

**Flight Priority:** medium

**ICESat-2 Tracks:** Y0422

**Remaining Design Issues:** none



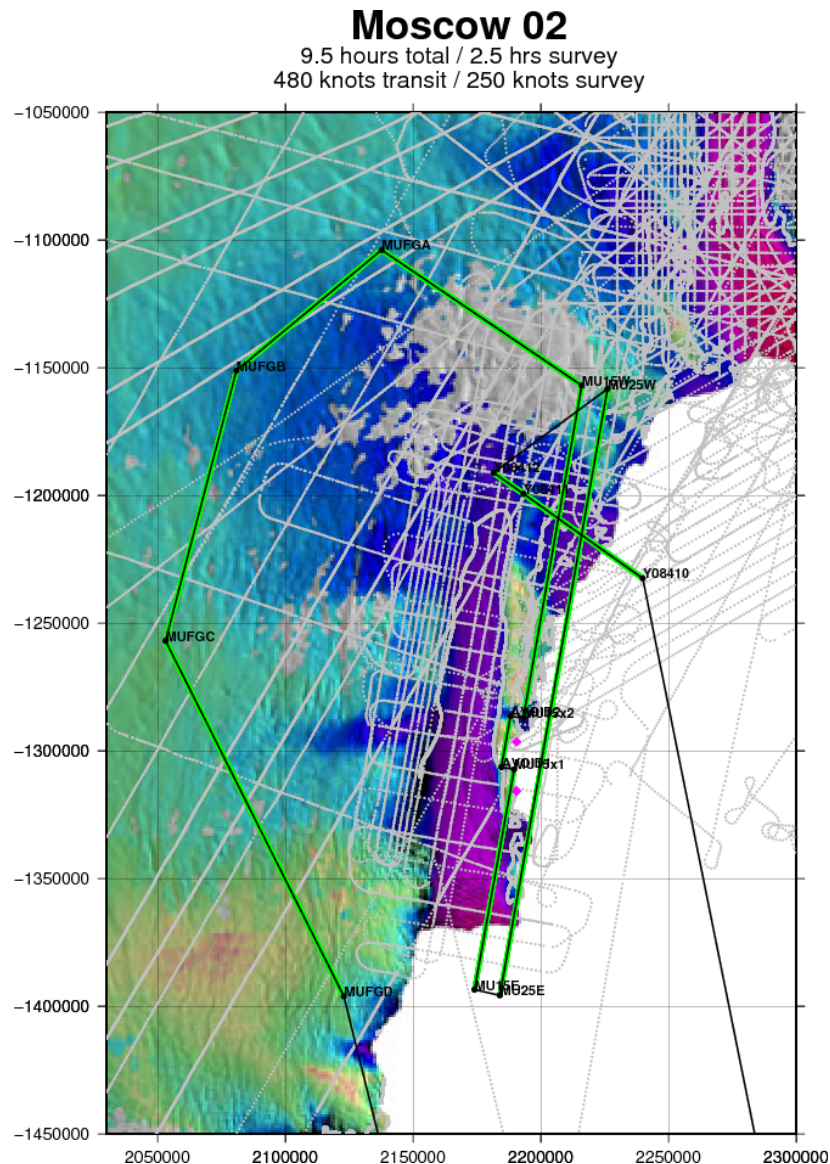
# Land Ice – Moscow 02

This mission is designed to survey portions of the Moscow University Ice Shelf and adjoining portions of the Sabrina Coast, in conjunction with the Moscow 01 flight. Both missions together yield a 5 km grid. We also fly a tie line along an ICESat-2 track. Finally we fly a flux gate inland of the ice shelf. This grid is designed to supplement earlier airborne measurements collected by the ICECAP Project.

**Flight Priority:** high

**ICESat-2 Tracks:** Y0841

**Remaining Design Issues:** none



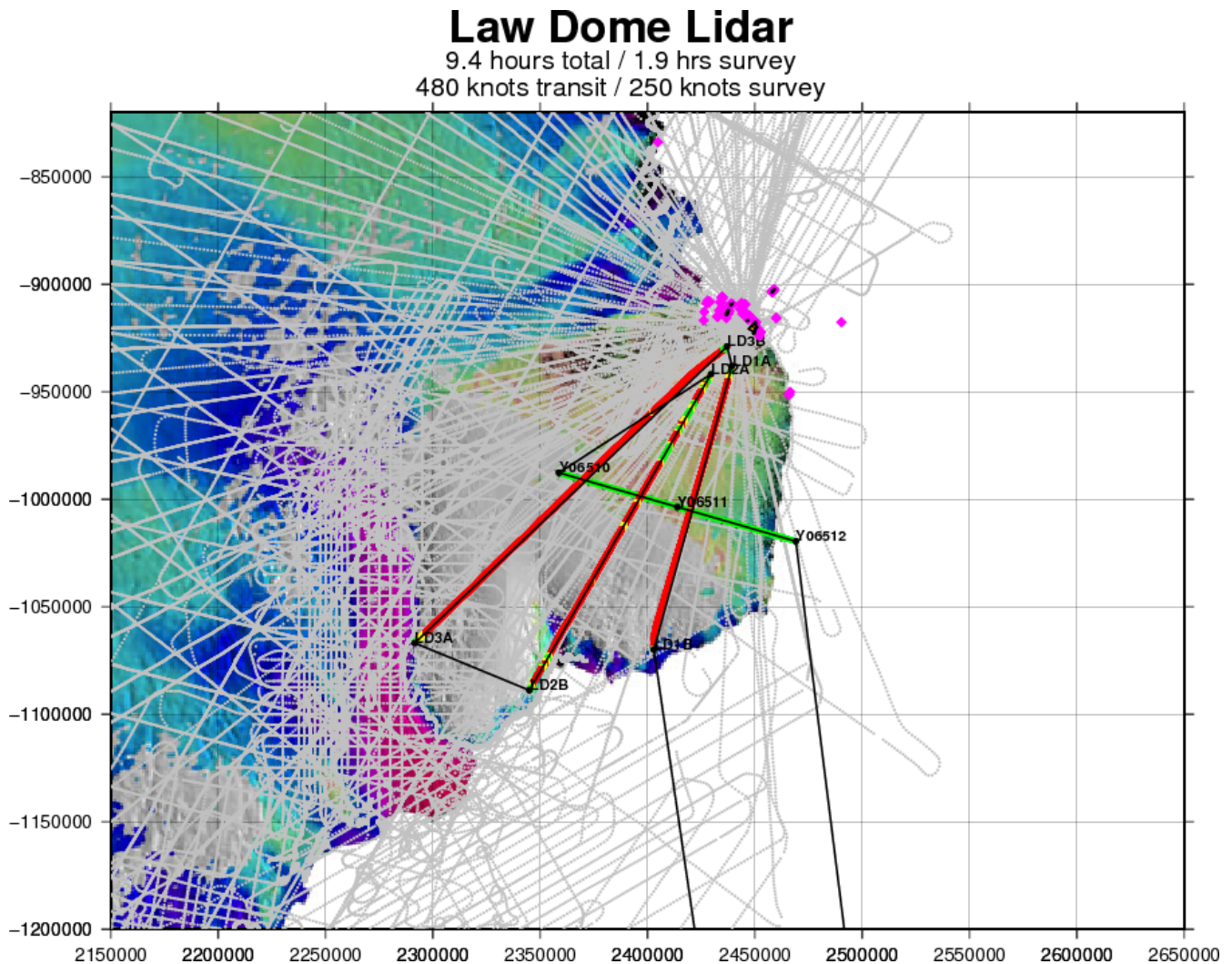
# Land Ice – Law Dome Lidar

This mission is designed to fly exact repeats of 20110122, 20110125, and 20121202 UTIG flights, all of which were equipped with photon-counting lidar. Law Dome has a large surface mass-balance gradient, and this gradient has changed between the ICESat-1 and ICESat-2 periods. Given the UTIG lasers, the OIB green laser, and many crossing IS-2 lines, this mission should allow testing of methods for identifying changing surface processes with green lasers.

**Flight Priority:** low

**ICESat-2 Tracks:** none

**Remaining Design Issues:** none



# Land Ice – Law Dome IS-2

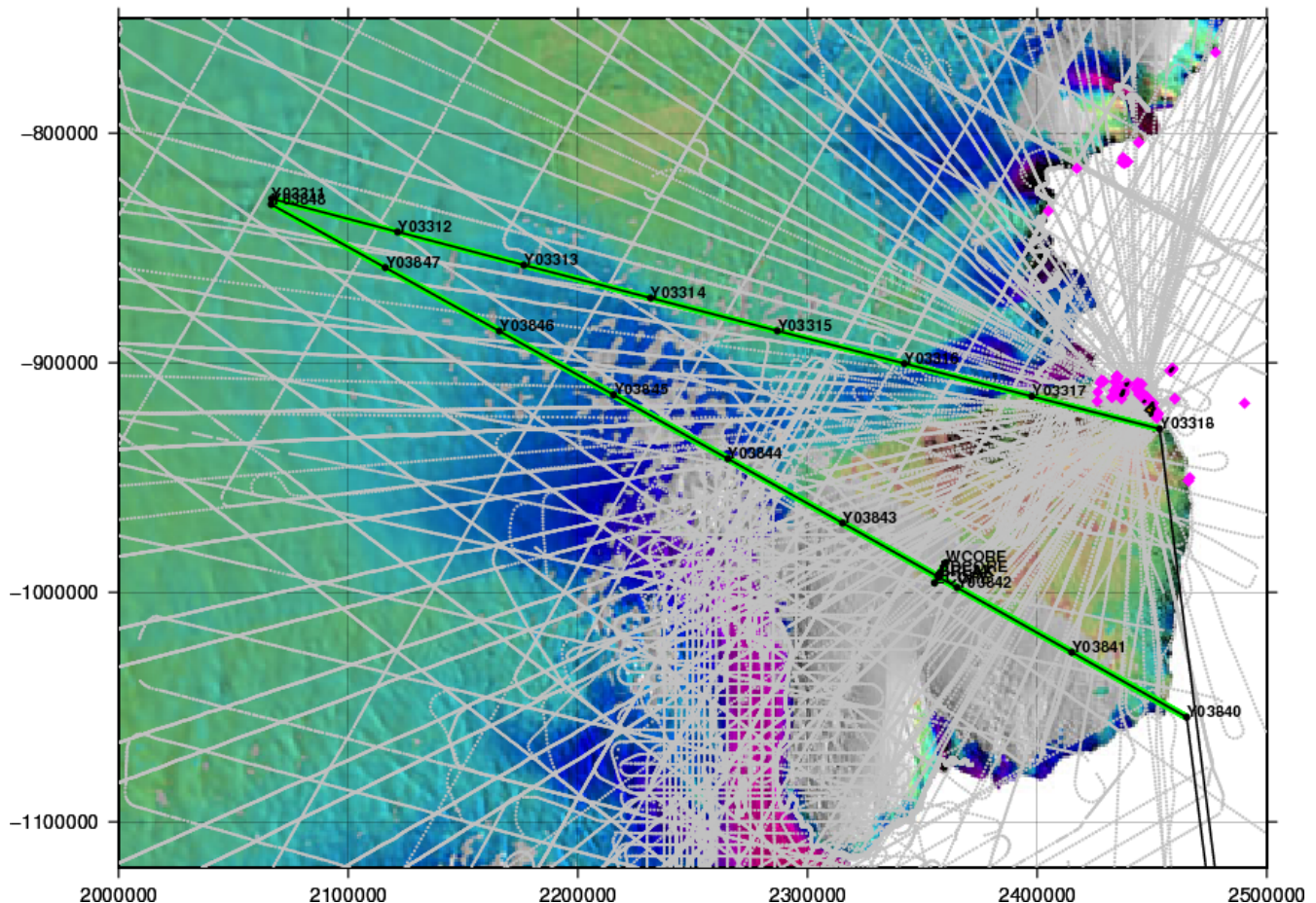
This mission is designed to fly over an ICESat-2 track across Law Dome. The flight also includes a direct overpass of the Law Dome ice core. We also fly an additional, low-latency IS-2 track for the return to the coast. This region shows some of the largest discrepancies between MERRA-2 and RACMO accumulations, and the proximity of this line to the core should allow an independent validation of the accumulation rates we measure. We specifically avoid fast flow regions with this flight, in order to maximize our chances of observing smooth firm stratigraphy.

**Flight Priority:** high

**ICESat-2 Tracks:** Y0384, Y0331

**Remaining Design Issues:** replace Y0331 with lower-latency IS-2 track if available; keep Y0384 unchanged

**Law Dome IS-2**  
9.8 hours total / 2.2 hrs survey  
480 knots transit / 250 knots survey



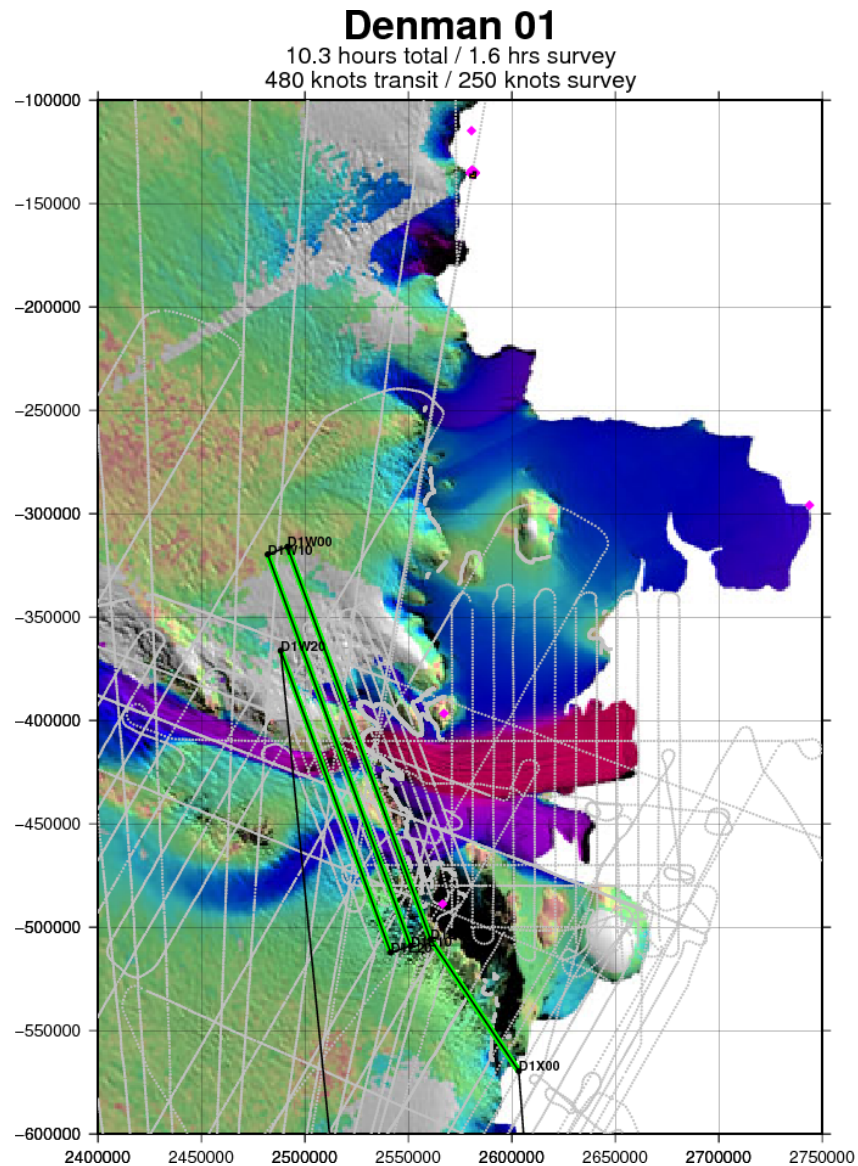
# Land Ice – Denman 01

This mission is designed to survey the neighboring Denman and Scott Glaciers, specifically the region just upstream of their grounding lines, on a 10 km grid. The grid is designed to supplement earlier airborne measurements collected by the ICECAP project, specifically by interleaving halfway between their flight lines.

**Flight Priority:** high

**ICESat-2 Tracks:** none

**Remaining Design Issues:** none



# Land Ice – Denman 02

This mission is designed to survey the centerlines of the Denman and Scott Glaciers from the edge of the Shackleton Ice Shelf to points above their fastest-flowing regions.

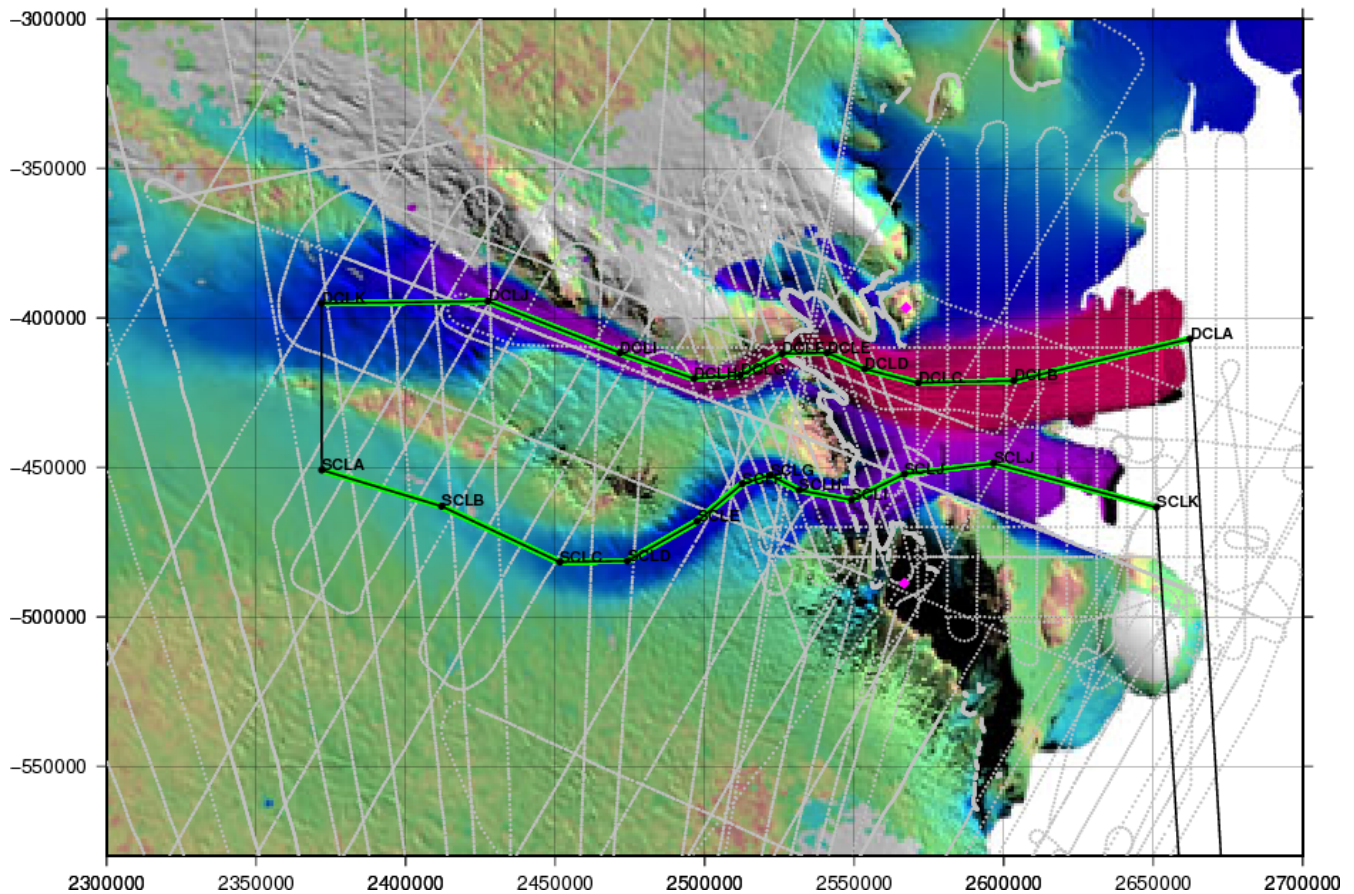
**Flight Priority:** medium

**ICESat-2 Tracks:** none

**Remaining Design Issues:** none

## Denman 02

10.2 hours total / 1.5 hrs survey  
480 knots transit / 250 knots survey



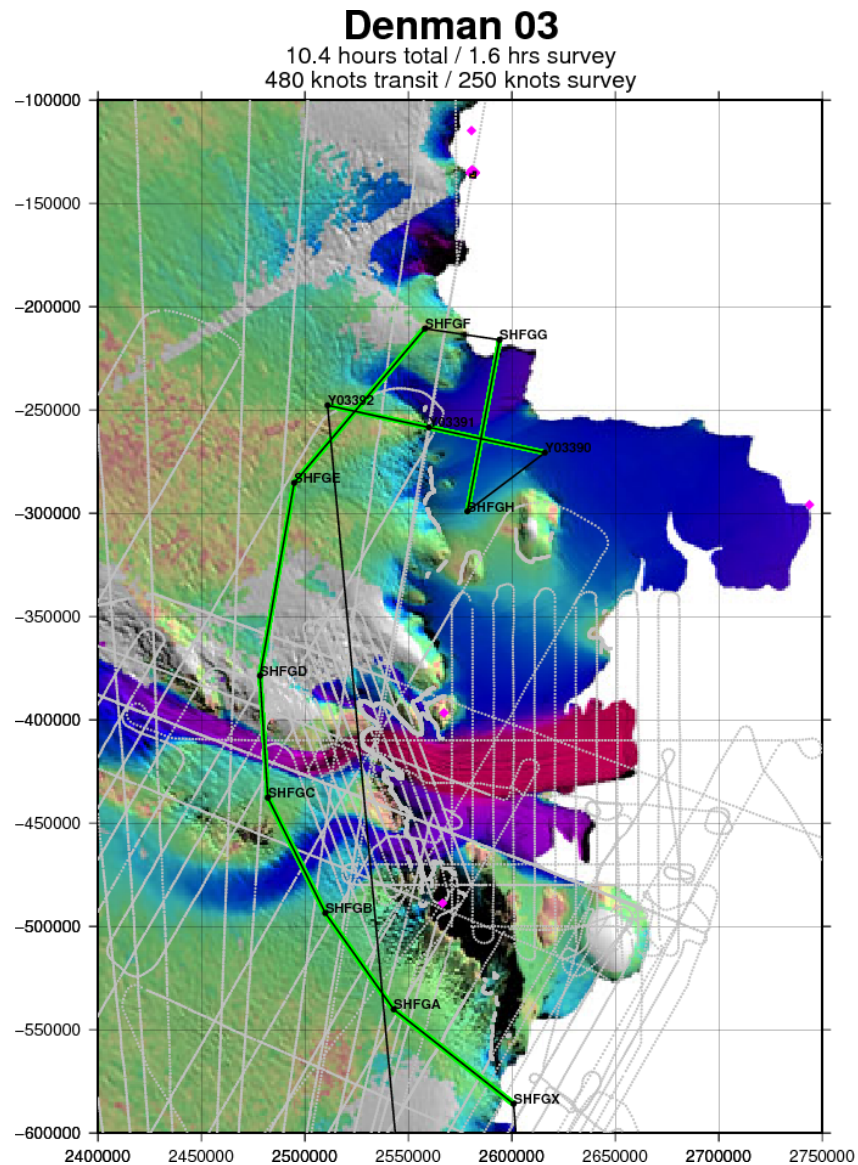
# Land Ice – Denman 03

This mission flies a fluxgate across the catchment area of the Shackleton Ice Shelf. We also fly a line across the floating shelf offshore of Roscoe Glacier, plus a tie line across this latter area along an ICESat-2 track.

**Flight Priority:** high

**ICESat-2 Tracks:** Y0339

**Remaining Design Issues:** none



# Appendix A: Status of Community Flight Requests

Requests for flight line modifications from the OIB science team are incorporated into the flight lines, in an interactive manner with the team through telecons and the planning meeting. The status of requests from researchers without an institutional connection to OIB, which are by nature less interactive, are summarized below. The color code below is as follows: green=request explicitly addressed in flight plans, blue=request could not be addressed, red=request yet to be addressed

none

# Appendix B: ICESat-2 Beam Patterns and OIB

The ICESat-2 ATLAS instrument emits 6 individual laser beams in a pattern fixed relative to the structure of the spacecraft. We refer to these 6 beams, when expressed in the frame of reference of the spacecraft itself (and NOT their positions on the earth's surface), as the “engineering beams”. The six beams are not identical – they are divided into “strong” and “weak” beams, three of each. Additionally two of the three “strong” beams are also known as TEP (Transmit Echo Path) beams, meaning that IceSat-2 records something similar to their start pulse waveforms. We also have a database known as the “reference ground track”, which are in fact the geodetic coordinates of the six beams along the surface of the earth. These are labeled with numbers 1, 2 and 3 designating, respectively, the left, center and right beam pairs, and by L and R within each pair designating the left or right beam. Thus the right beam of the center (nadir) beam pair is 2R, and the left beam of the right beam pair is 3L. For this discussion, the terms “left” and “right” are from the perspective of a person facing the direction of travel of the spacecraft.

Since the yaw attitude of the spacecraft is not fixed, the relationship between the six engineering beams and the six reference ground tracks are also not fixed, and we seek to understand how to map the engineering beams to the reference ground tracks in a simple and reliable manner. This is necessary because the 6 engineering beams are not identical to each other.

The six engineering beams are arranged in three pairs, with two near nadir, two at spacecraft left, and two at spacecraft right. The beams are labeled numerically 1-6. Each pair has one strong and one weak beam. The strong beams are the odd-numbered beams 1, 3 and 5, while the weak beams are the even-numbered beams 2, 4 and 6. The TEP beams are 1 and 3. The beam pairs are separated by ~3.3 km across-track, and the two beams in each pair are separated by ~90 m. But depending on the yaw attitude of the spacecraft, the relative locations on the ground of the strong and weak beams, and two TEP beams, varies.

For the reference ground tracks, the six beam paths (1L,1R,2L,2R,3L and 3R) are invariant with spacecraft attitude. Beam 2L, for instance, is always the left beam of the center beam pair, though beam 2L might correspond to different engineering beams depending on the spacecraft's yaw attitude. Figure B1 below depicts the reference ground track geometry for one ascending track near Summit Camp, Greenland.

For the purposes of ATM and OIB, we must identify reference ground tracks by single characters rather than the two-character 1L etc scheme, due to a number of different software limitations. So internally, we replace 1L with A, 1R with B, etc through 3R with F. For flight planning purposes, we also have three “virtual” reference ground tracks, X, Y and Z. Each corresponds to the centerline of a beam pair, with X for the left beam pair centerline, Y for the center pair, and Z for the right pair. This is in response to a recommendation from the OIB science team to fly the centerlines of the beam pairs in certain circumstances, rather than center the aircraft on specific individual beams. Figure B1 also shows the correspondence between the internal beam letters (A-F) in the reference ground track and the more generally-used two-character scheme.

For the fall 2019 Operation IceBridge deployment time frame, the yaw orientation is expected to remain in the “+X” orientation for the duration of the campaign. In this orientation, the three strong beams lead the three weak beams along-track, the strong beams are the left beams of each pair, and the weak beams are the right beams of each pair. Furthermore, the TEP beams in this yaw orientation

correspond to beams 1L and 2L in the reference ground track. See Figure B2 below for a depiction of the engineering beam geometry for the +X spacecraft orientation.

Table B1 below shows the mapping between engineering beams and reference ground track designations for the +X yaw orientation. The two colors in the table indicate that items highlighted in the same color remain in lockstep regardless of the spacecraft's yaw attitude, while items in different colors change in their relation to each other when yaw orientation changes. For instance, ref track ID 2R always corresponds to internal ref track letter D, and engineering beam 3 is always a strong beam with TEP. But the laser occupying ref track 2R is not always strong beam #3.

Table B1. Beam mapping for +X orientation.

Ref track ID	Ref track letter (OIB internal)	Engineering beam #	Beam type	TEP
1L	A	6	weak	no
1R	B	5	strong	no
2L	C	4	weak	no
2R	D	3	strong	yes
3L	E	2	weak	no
3R	F	1	strong	yes

Table B2, below, identifies the geometric meaning of the “virtual” reference track letters X, Y and Z, which are the centerlines of the respective beam pairs. These are created (internal to ATM/OIB) for flight planning purposes because of a recommendation from the OIB science team that, in some cases, we place the aircraft not over a specific beam but over the center of a given beam pair. This is usually intended to maximize our chances of covering both beams of a pair with the ATM wide scanner (~250 m in width).

Table B2. OIB's virtual reference ground tracks.

Virtual track letter (OIB internal)	Corresponds to beam pair centerline
X	Left / 1
Y	Center / 2
Z	Right / 3

# IceSat-2 at Greenland Summit

Red:A(1L), Green:B(1R), Blue:C(2L), Orange:D(2R), Magenta:E(3L), Cyan:F(3R)

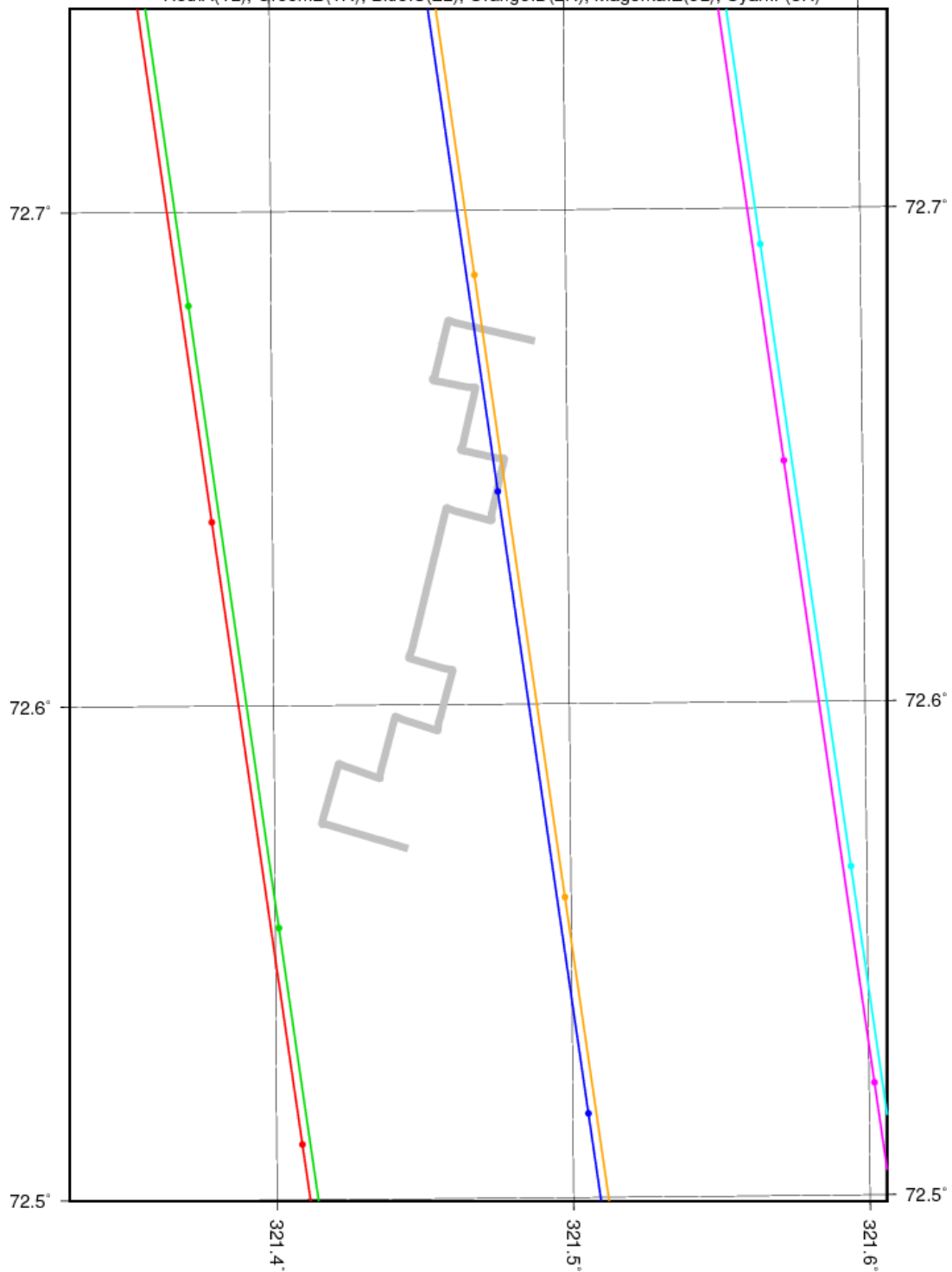


Figure B1. Ascending ICESat-2 reference ground tracks (ref orbit #0749) at Summit, Greenland.

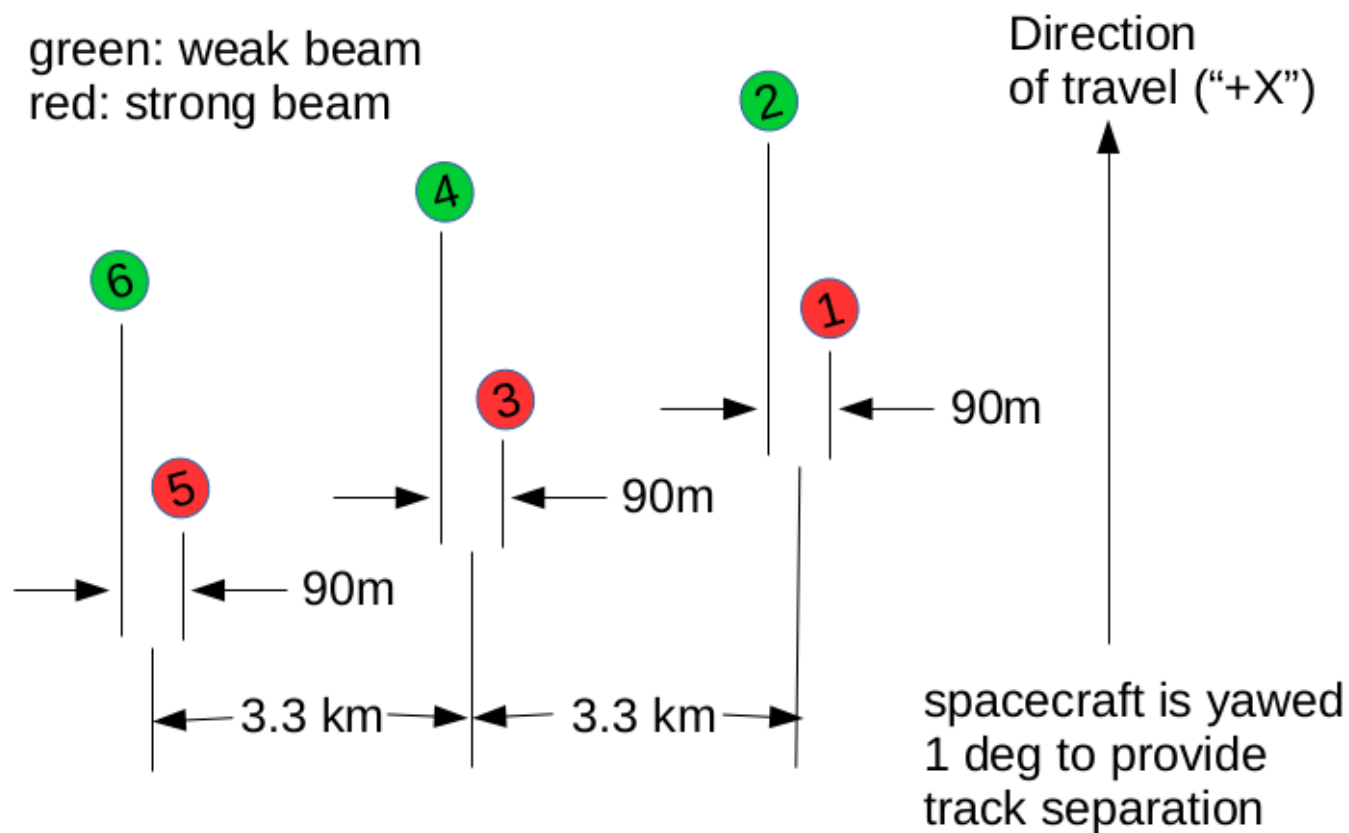


Figure B2. Spacecraft beam pattern for +X orientation.

# Appendix C: Sea ice drift corrections

For 2018 and 2019, a requirement arose from the OIB science team to apply “drift corrections” to some of our planned flight paths. These corrections apply to all sea ice missions that include a low-latency ICESat-2 component.

The purpose of the corrections is to modify our flight paths, according to the time differences between the expected time of our aircraft’s arrival at each of our waypoints and the overflight time of the ICESat-2 spacecraft, and according to the expected drift velocity of the sea ice. At each waypoint, the drift correction yields a position offset which can be applied in real-time as we fly. The result is that we improve the chance that our aircraft and the spacecraft measure the same swath of sea ice within a few hours, even as the ice itself drifts according to winds and currents.

An important component of the drift correction arises from the surface winds. Since the G-V has real-time winds readily available to the flight crew and hence to the instrument team, we can use winds measured in-situ and in real time to inform the drift correction. Since we measure winds at altitude, while the surface winds are what is required, we will apply altitude-dependent scaling corrections to the wind speed as part of the drift correction algorithm.

Although we have a drift correction procedure based on these principles available, we have elected not to apply it for this project’s sea ice missions. The reason is that our knowledge of drift properties of Antarctic sea ice is limited, making our correct algorithm’s effectiveness difficult to ascertain. Instead, we intend to account for drift solely by offsetting the “racetrack” pattern’s individual legs as explained in the third paragraph of Appendix D. This approach used modeled wind direction to generate the offset direction.

# Appendix D: Design considerations for ICESat-2 sea ice missions

The IceBridge and ICESat-2 sea ice science team members have agreed that OIB should be prepared to fly as many as five dedicated ICESat-2 low-latency missions, in addition to the regular OIB sea ice survey missions. Three of these should be considered baseline-priority missions, and two as high-priority missions. We also hope to work low-latency IS-2 tracks into regular OIB missions as practical. But for the dedicated IS-2 missions, the design trade space is potentially enormous. Since these missions have to be designed close in time to the date on which they are to be flown (due to changing weather and orbital geometry and timing considerations), here we provide a “cookbook” for designing up to five of these missions.

Several of the sea ice missions will be “walking-racetrack” style flights, intended to obtain very broad coverage over TEP beams D (“2R” to the IS-2 community) and F (“3R”). We place a single ~200 km pass over a drift-corrected, low-latency beam A and beam C flown in opposite directions (thus the “racetrack” analogy), then “walk” that racetrack pattern in a direction perpendicular to the ground track so that successive passes are offset to one or each side, depending on wind. The degree of offset should yield overlap of adjacent ATM wide-scan (T6) swaths of 15%. The racetracks should be flown at an altitude of 1000m, yielding a T6 swath of 500m and an overlap of 75m. Therefore the offset between adjacent flight lines should be 425m. We will perform a single discrete drift correction, using modeled surface winds obtained prior to takeoff, and calculated for the time elapsed between the spacecraft’s passage overhead and the time of our aircraft’s arrival on-site.

The racetrack pattern depends on winds. If the cross-track (relative to the IS-2 reference ground track) wind component is less than 3 knots, we drift-correct the D and F ground tracks according to modeled winds obtained prior to takeoff and our expected arrival time, and then offset the racetrack pattern 425m to the east, and then 425m to the west, for three circuits. If the cross-track wind component is greater than 3 knots and westerly, we drift-correct as above, then we further offset the reference tracks 50m west (upwind), offset the next pattern 425m to the east, and the third 850m to the east (walking the pattern downwind with time). If the winds are easterly and >3 knots cross-track, we do the reverse of the above. To account for differences in distance to and from Thule, we simply adjust the length of the racetrack legs accordingly.

# **Appendix E: WorldView / ICESat-2/ OIB coordination**

As of this writing, no requests for Worldview coordination have been made. In case they are, the procedure below will be followed.

The OIB science team (and others) requested that OIB data collection over ICESat-2 lines, on Arctic sea ice, be coordinated with WorldView satellite imagery collection as well. This effort is complicated by the fact that, for OIB, the IS-2 underflight lines are planned just a few days prior to the flight. This schedule is driven primarily by uncertainty in weather forecasts – we plan the underflights only when we believe that we have a reasonable chance of actually executing them. In practice, this means that we most often plan IS-2 underflights 1-2 days prior.

Given that, our plan for accomplishing the WorldView coordination is as follows. On a given day of the OIB Antarctic campaign when sea ice flights are possible, we will consult weather forecast models and IS-2 orbit predictions, determining if any suitable coordinated sea ice underflights are likely to be successful two days hence (clear skies for both aircraft and spacecraft to see the surface). Between 1 and 3 OIB flight plans for that day will be generated, incorporating the low-latency IS-2 tracks. These flight plans, or their most relevant portions, will be sent via email to our WorldView targeting contacts (Steven Hak, [jhak@usgs.gov](mailto:jhak@usgs.gov)). Since we will be in-flight from roughly 1100 to 1900 UTC on these days, we will be able to send them only after we land, giving our WorldView contact(s) on the order of 36 hours to process the targeting requests.

# Appendix F: Avoidance of Wildlife and Other Protected Areas

Flight operations over Antarctica are restricted by several factors unique to Antarctica. Some of these factors stem from the fact that the United States is a signatory of the Antarctic Treaty, and certain portions of the Treaty require the signatories to protect wildlife and other designated areas of particular value. In practice, this means that OIB must avoid overflying known wildlife colonies, Antarctic Specially Protected/Managed Areas (ASPAs and ASMAs), and certain other sites, below specified AGL altitudes. In summer of 2014, the OIB Project Science Office completed a contractual arrangement with UK-based Environmental Research & Assessment (ERA) to obtain their database of Antarctic wildlife colony locations and specially protected areas. We have obtained an updated version of this database annually since then. We then incorporated an automated analysis which compared planned flights with the colony locations and with the ASPAs/ASMAs into the planning process for each flight. Based on that analysis, we adjusted several flight lines to avoid the indicated areas with explicit maneuvers and waypoints. The waypoints are labeled “AVOIDx” to cue navigators and flight crews to the urgency of avoiding the nearby areas. Even with these adjustments, however, it is impossible to predict the exact flight path of the aircraft in advance, and for this reason we specify a plan here to avoid all known areas with relevant flight restrictions.

The OIB science navigators will display point locations of all known wildlife colonies, and polygons defining the ASPA/ASMA boundaries, on an instance of the Soxmap navigation display and will monitor it carefully, calling out to the flight crew when an undesired upcoming overflight is foreseen. For the wildlife colonies, we use a lateral “stay-out” radius and a minimum overflight altitude somewhat more conservative than the ones used by ERA for their analysis. Thus, each colony location will be at the base of a three-dimensional cylinder which the aircraft will remain well-clear of. For the ASPA polygons, each one has its own overflight restrictions, and a comprehensive database listing these details may not be available in-flight. Thus we plan to steer clear of all ASPAs and ASMAs unless we know the permissible minimum altitude for a particular ASPA.

Our procedures for avoiding wildlife and ASPAs/ASMAs are as follows:

1. No overflights of wildlife colonies below 1000 m AGL within a radius of 2 km
2. No overflights of ASPAs/ASMAs at any altitude unless we know overflight is permitted for that particular area at a particular altitude.

We also expect that the flight crew can display the wildlife locations and ASPAs/ASMAs on their flight instruments, providing an independent and redundant avoidance technique.